State of Illinois
Department of Natural Resources

ISWS CONTRACT REPORT 2018-02
AUGUST 2018

# WATER SUPPLY PLANNING: MIDDLE ILLINOIS ASSESSMENT OF WATER RESOURCES FOR WATER SUPPLY

FINAL REPORT

Walt Kelly • Daniel Abrams • Vern Knapp • Zhenxing Zhang • Benedykt Dziegielewski
Daniel Hadley • George Roadcap • Devin Mannix • Yanqing Lian • Scott Meyer • Jason Thomason

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Illinois Department of Natural Resources
Office of Water Resources

Printed by Authority of the State of Illinois • DNR-OWR-19-0073 • 11/18 • IOCI 19-0329

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Walton R. Kelly
Daniel B. Abrams
H. Vernon Knapp
Zhenxing Zhang
Benedykt Dziegielewski
Daniel R. Hadley
George S. Roadcap
Devin H. Mannix
Yanqing Lian
Scott C. Meyer
Jason F. Thomason

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Illinois State Water Survey
Illinois State Geological Survey
Prairie Research Institute
University of Illinois at Urbana-Champaign

Funded by:
Illinois Department of Natural Resources
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# Contents

# Contents (Concluded)

# List of Figures

Page

# List of Figures

# List of Figures

# List of Tables

Page

## Abstract

This report examines the impacts of current and future demands on water supplies for the Middle Illinois Water Supply Planning Region (WSPR) in central Illinois, an area comprising seven counties: LaSalle, Livingston, Marshall, Peoria, Putnam, Stark, and Woodford.

Initial water demand scenarios were developed out to 2060 for the five major water sectors, including thermoelectric power generation, public supply, self-supplied domestic, self-supplied industrial and commercial (IC), and self-supplied irrigation, livestock, and environmental (ILE), and are described in a companion report (Meyer et al., In press). Thermoelectric power-generation facilities located adjacent to the Illinois River dominate present and future demand in the region. Current water usage is an estimated 588 Mgd, or 76 percent of the region's use. Self-supplied IC accounts for the second largest demand, at 17 percent. Public supply accounts for 5 percent, ILE uses 1 percent, and the domestic sector uses less than 1 percent.

Significant water resources are available to meet demands in the Middle Illinois WSPR, including both groundwater and surface water. Most of the region can use groundwater resources from two major aquifer systems. There are substantial productive sand and gravel aquifers in the region, primarily in the Illinois River Valley, but also in western Woodford County, eastern and western Livingston County, and northwestern LaSalle County. The deeper Cambrian-Ordovician sandstone aquifer system is productive throughout the region, although its usefulness decreases farther south because of increasing depth and salinity.

Sand and gravel aquifers should be sufficient to meet their projected demands, at least on a regional scale. Local issues regarding the sand and gravel aquifers may still occur because of the tight clustering of well fields, the variable quality and saturated thickness of the sands and gravels along the Illinois River, variability of the Illinois River stage, and elevated chloride concentrations. There are 28 public water supply systems using sand and gravel aquifers that could be considered at risk, either from falling water levels, relatively unproductive aquifers, high demands, or vulnerability to contamination. LaSalle and Sparland were identified as being sensitive to both future water demand and water quality concerns.

In most of the region, the sandstone aquifers are projected to have enough water to satisfy demands to 2060. The area of greatest concern, however, is in east-central LaSalle County along the Illinois River where the sandstone is not hydrologically connected to the Illinois River. Increasing demands, such as from industrial growth, might cause head declines that could put the St. Peter Sandstone at risk of going dry locally and reduce the productivity of wells in the lower Ironton-Galesville aquifer.

Both aquifer systems have some water quality issues of concern. Nitrate and arsenic are the main concerns as to the sand and gravel aquifers. The main water quality concerns regarding the sandstone aquifers are radium, salinity, and fluoride.

The primary surface water sources in the Middle Illinois WSPR are the Illinois and Vermilion Rivers. The Illinois River generally provides a sufficient and reliable water supply for public water supply and industry. The supply is sufficient to meet Peoria's surface water demands for public supply. However, water withdrawal for thermoelectric power generation could be restricted because of low flows set by permits and high water temperatures during drought conditions.

The Vermilion River provides an adequate water supply for Pontiac and Streator public water systems. The water supply in both cities is enhanced by off-stream reservoirs and ion exchange systems for both water quantity and quality purposes. The Pontiac public supply system is classified as at risk, but could be marginally adequate if an ion exchange system is installed. The Streator public supply system is considered adequate. However, Pontiac and Streator withdrawals may potentially cause adverse impacts on aquatic ecosystems in the Vermilion River.

Changes to the Lake Michigan diversion have altered the low flow conditions in the Illinois River. With the decreasing diversion from Lake Michigan, the lowest flow amounts along the Illinois River are expected to decrease again in the near future. Although these changes do not limit the availability of flow to meet most water supply needs, they can pose challenges for low flow and protected flow management of the river.

During low flow conditions, operation of the powerhouse at Lockport, which is upstream of the Middle Illinois WSPR, can create sizeable fluctuations in the amount of water released and available to downstream users. At each successive downstream lock and dam on the Des Plaines and Upper Illinois Rivers, operations by the U.S. Army Corps of Engineers appear to effectively pass these fluctuations downstream while attempting to maintain the target pool level behind each dam. An existing unsteady flow routing model for the Illinois River was used to replicate these operating conditions, focusing specifically on the Marseilles dam and pool within the WSPR. This model was also used to investigate the impacts related to selected alternative operation scenarios. These scenarios suggest that there is the potential to incrementally attenuate the low flow fluctuation at each successive downstream dam through modest changes in pool-level management. This study did not attempt to evaluate the possibility that modifications could also be made at Lockport to reduce the amplitude of the flow fluctuations.

# 1 Introduction

Water is an essential part of all life. The availability and sustainability of an adequate and dependable water supply is essential for our public, environmental, and economic health. This important understanding led to the initiation, under direction of Executive Order 2006-01 from the Governor of Illinois, of a program for comprehensive regional water supply planning and management in Illinois. Under the framework of the order, the Illinois Department of Natural Resources’ Office of Water Resources (IDNR-OWR) directs this effort. The Illinois State Water Survey (ISWS) and Illinois State Geological Survey (ISGS), both within the University of Illinois’ Prairie Research Institute, are responsible for quantifying the available water supply, which includes collecting and interpreting the scientific data and developing water supply computer models. The state has been divided up into ten water supply planning areas, and regional water supply planning has been completed in three of these: (1) Northeastern Illinois (CMAP, 2010, Meyer et al., 2012); (2) East Central Illinois (East-Central Illinois Regional Water Supply Planning Committee, 2009, 2015, Roadcap et al., 2013); and (3) the Kaskaskia River Basin (Kaskaskia Basin Water Supply Planning Committee, 2012, Knapp, 2017, Knapp et al., 2012).

This report focuses on the technical aspects of water supply assessment for the Middle Illinois River Water Supply Planning Region (WSPR) in central Illinois, an area comprising seven counties: LaSalle, Livingston, Marshall, Peoria, Putnam, Stark, and Woodford (Figure 1). Woodford County was included in the East Central Illinois water supply report, but is also included in this report because of overlapping planning priorities with other counties in the Middle Illinois WSPR. The results of our scientific analyses are intended to highlight the opportunities and challenges ahead for meeting future water demand in the Middle Illinois WSPR.

Stakeholder water supply planning committees have been created in each priority planning area and are tasked with developing regional water supply planning and management recommendations in accordance with existing laws, regulations, and property rights. Under the guidance of the Tri-County Regional Planning Commission based in Peoria, a grassroots water supply planning group was formed for the Middle Illinois WSPR, called the Middle Illinois Regional Water Supply Planning Committee (RWSPC). The ISWS and ISGS, along with the IDNR-OWR, are responsible for providing technical support to the RWSPC and updating and expanding regional water resource information.

Each RWSPC is charged with developing a regional water supply plan that clearly describes water supply and demand issues of the region under study. IDNR-OWR suggests that the regional plans address at least the following principal components:

- Descriptions of the sources of water available to the region;
- Plausible estimates of how much water may be needed to the year 2060;
- Estimates of the impacts of withdrawing sufficient water to meet demand; and
- Descriptions of options for providing additional sources of water and/or decreasing demand.

The ISWS and ISGS were assigned the responsibility of developing initial water demand scenarios to 2060, with the RWSPC reviewing and adjusting the scenarios using local knowledge. A draft water demand report was developed in 2015 (Meyer et al., 2015). Unfortunately, state funding shortfalls forced the RWSPC to suspend activities in 2015. The

ISWS, however, continued working on groundwater and surface water studies for the region and published the water supply planning progress report in 2016 (Kelly et al., 2016). The water supply planning process was reinitiated in 2017, and the RWSPC provided comments on the draft water demand report in March 2018. The final water demand report for the Middle Illinois WSPR is in the process of being published (Meyer et al., In press). This report incorporates updated model results based on the final water demand scenarios and expands the water supply planning progress report (Kelly et al., 2016)

## 1.1 Study Area

Seven counties are in the Middle Illinois WSPR of central Illinois: LaSalle, Livingston, Marshall, Peoria, Putnam, Stark, and Woodford (Figure 2). Peoria is the largest city in the region; other major cities include LaSalle, Ottawa, Peru, Pontiac, and Streator. The region comprises the upper reach of the Illinois River watershed. Other major watersheds in the region include the Vermilion River and the lower Fox River. There are two major aquifer systems in the region, the shallow sand and gravel aquifers and deeper bedrock aquifers. The shallow aquifers were deposited by glaciers or rivers, and the most productive of these are in the Illinois River valley north of Peoria. Bedrock aquifers are found throughout the region, at or near the land surface in northern LaSalle County, but much deeper in the rest of the region.

The assessment of water supply impacts focuses on both surface water and groundwater resources. Pontiac, Streator, and power-generating facilities rely on surface water resources, while most of the remaining municipalities and industrial and commercial facilities rely on groundwater. Peoria uses both surface water and groundwater for its supply.

## 1.2 Report Structure

The next section of this report, Section 2, provides a general discussion on water supply and demand, presents a brief presentation of the three scenarios describing future water demands to 2060, developed for the RWSPC, and describes how those scenarios were incorporated into analytic models to assess impacts.

The focus of Section 3 is groundwater availability. The section begins with a description of the aquifers in the region, overviews of the regional geology and hydrogeology, and an introduction to the numerical groundwater flow model, which was developed to understand flow in the aquifers and forecast the impacts of future demands. Discussion of groundwater conditions is separated into three sections: sand and gravel aquifers, shallow bedrock, and deep bedrock. Shallow bedrock aquifers are used only sparingly in the region, and thus are discussed only briefly and are not included in model simulations. Because the other two aquifer systems behave independently of each other, results of model simulations and calibration are reported separately. The flow model analysis emphasizes the impacts of future water supply demands on the aquifers, based largely on currently active wells, and includes a description of likely impacts based on prospective locations of potential new high-capacity wellfields. Although this report focuses on water quantity, we also include short summaries of water quality in the major aquifer systems.

Section 4 focuses on surface water availability, emphasizing the analytical methods used to determine river yields, uncertainties in data inputs, and the use of statistical methods to estimate the 90 percent confidence yields. For each of the major public surface water supplies (Peoria, Pontiac, and Streator), a summary is presented that includes discussions of data inputs, comparisons of historical drought periods, possible characteristics of worse-case droughts, results of the yield analyses, and finally, the expected drawdowns during the droughts of record.

Section 5 presents a general summary of water resource availability and recommendations for further study.

## 1.3 Caveats

The primary focus of the water supply planning initiative is on water quantity. Although water quality is not emphasized in this planning effort, water quality issues are reported where existing relevant information is known to the ISWS. Given the expertise available in the state surveys and the resources and time available to conduct the necessary studies, the following is a list of topics that are important in regional water supply planning and management, but are not addressed comprehensively in this report:

- Economics
- Legal matters
- Societal and ethical issues and values
- Water infrastructure
- Water treatment
- Water losses
- Consumptive water use
- Storm water and floods
- Utility operations
- Conservation and water reuse
- In-stream water uses (ecosystems, recreation, navigation, etc.)
- Governance and management

Surface and groundwater models were developed using the most accurate available knowledge of regional hydrologic conditions. Although the results represent a range of important impacts of the withdrawals simulated in the study, new information and more powerful tools could produce different results from those expressed in this report.

## 1.4 How Much Water is Available in the Middle Illinois WSPR?

The amount of water that the streams and aquifers of the Middle Illinois WSPR can supply depends on where the demand is, how much money users are willing to spend, and what societal and environmental consequences are acceptable. The amount of water available fluctuates. Many water development projects act to increase water availability by capturing water that would otherwise be lost to flood flows or evaporation. Other projects and hydrologic processes act to decrease water availability, such as reservoir siltation or aquifer desaturation. Future increases in water demand and water development projects will take place on a landscape where water is already heavily managed by drainage networks, dredged streams, reservoirs, water withdrawals, and wastewater discharges. Unlike other natural resources that humans consume, such as petroleum, only a tiny amount of the mass of water used is converted to other compounds (such as hydrogen or oxygen gas). Most of the water we consume is returned to the hydrologic cycle through wastewater discharge or evaporation.

In this study, we examine the impact of current and future water demands on the streams and aquifers in east-central Illinois through the use of computer-based models. Current water demands were estimated from annual surveys of large water users conducted by the Illinois Water Inventory Program (IWIP) at the ISWS. Future water demands were estimated by the ISWS with input from the RWSPC, and are detailed in the report “Water Demand in the Middle

Illinois Water Supply Planning Region, 2010-2060" (Meyer et al., In press). The modeling and analysis of groundwater and surface water in this study were conducted separately because of the fundamental difference in their hydrologic behavior and the analytical tools used to evaluate each. Surface water supplies are strongly influenced by the timing and magnitude of precipitation events and thus we chose to model them with transient simulations and statistical analyses of past streamflow records using the analytical Illinois Streamflow Assessment Model (ILSAM). Groundwater supplies exhibit more steady hydraulic behavior but vast variability in the spatial geometry of the aquifer materials, so we chose to model the aquifers with a deterministic numerical groundwater flow model, MODFLOW (McDonald and Harbaugh, 1988). Results of the ILSAM model were used to calibrate flow budgets in the MODFLOW model.

Where do scientists, and more importantly the public, draw the line as to what is or is not an acceptable impact? If impacts suggested by the models are considered by stakeholders (in this case, represented by the RWSPC) to be unacceptable or too uncertain, they may recommend to adopt policies and target monitoring and water management efforts to track and mitigate impacts regionally or in specific affected areas, or to conduct additional studies to reduce uncertainty. The models developed for this project are intended to be used for future analysis of other scenarios to test the effects of alternative management strategies.

### *1.4.1 Acknowledgments*

This project was funded, in part, by the IDNR-OWR and by General Revenue Funds of the State of Illinois.

Several staff members of the Illinois State Water and Geological Surveys assisted with the project. Kevin Rennels and Kenneth Hlinka collected groundwater-level data. Conor Healy provided water use data through the Illinois Water Inventory Program (IWIP). Greg Rogers and Brad Larson assisted with the ILSAM model preparation, ISGS geologic data, and interpretations. Technical reviews were provided by Kenneth Hlinka, Elias Getahun, and Laura Keefer. Lisa Sheppard provided technical editing.

The report was prepared under the general supervision of ISWS Director Kevin O'Brien. The views expressed in this report are those of the authors and do not necessarily reflect the views of the Illinois State Water Survey, the Illinois State Geological Survey, or the Prairie Research Institute.

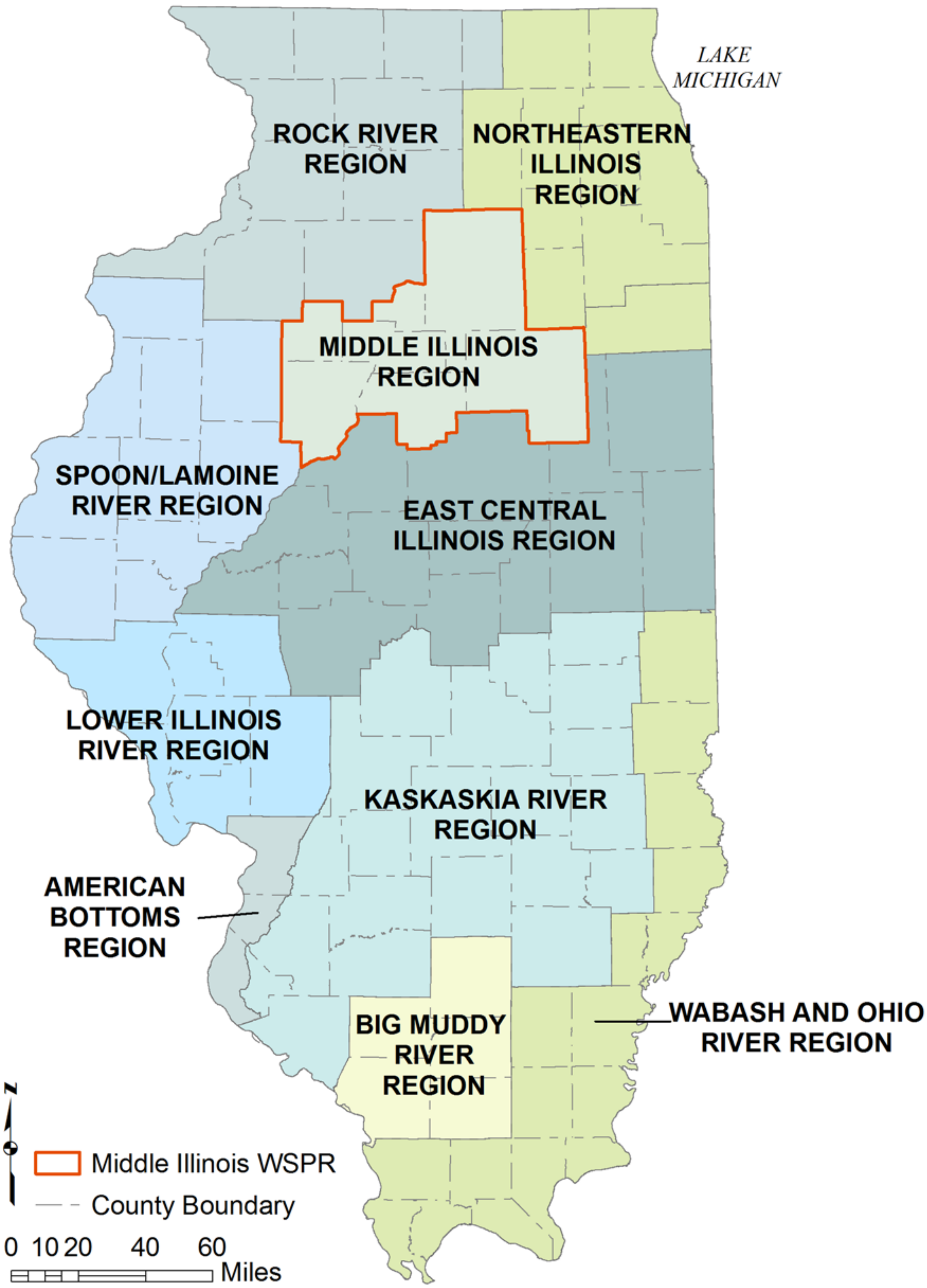


Figure 1. Water supply planning regions (WSPRs) in Illinois

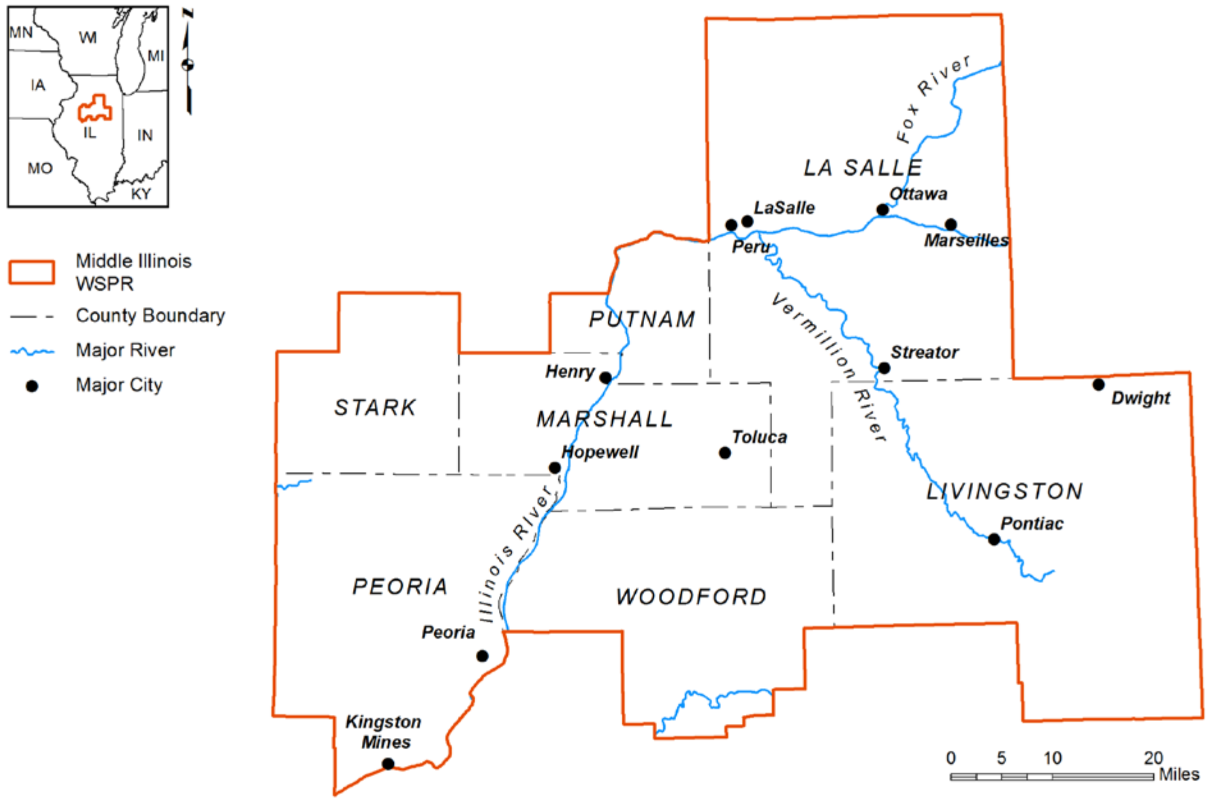


Figure 2. Map showing the seven counties, major rivers, and major cities in the Middle Illinois WSPR

# 2 Water Use and Demand Projections for the Middle Illinois WSPR

## 2.1 Water Use in the Middle Illinois WSPR

This study is focused on the availability of water for withdrawal from groundwater and surface water resources within the Middle Illinois WSPR for various uses. Other aspects of water resources in the region, such as the valuable instream uses of surface water in which water is not withdrawn from the water body, such as that used for navigation, fish and wildlife preservation, recreation, water quality, and hydroelectric power generation, are not addressed in this study.

The various uses of withdrawn water are separated into five water-demand sectors: (1) public supply; (2) self-supplied domestic; (3) self-supplied thermoelectric power generation; (4) self-supplied industrial and commercial; and (5) self-supplied irrigation, livestock, and environmental. Figure 3 shows the distribution of water use in the region by sector for the year 2010. As is discussed later, the separation of water-demand sectors is occasionally imprecise when water is withdrawn for multiple purposes; for example, much of the water classified as industrial-commercial is used in generating power for a large industry. Also, a sizeable portion of the public supply is sold to industrial and commercial facilities. The demand projection study used the 2010 water demand as the benchmark for describing current use and projecting future demands (Meyer et al., In press). Changes in demand since 2010 are noted when they depart from their expected range in variability.

The Illinois River is the centerpiece for much of the water demand and availability within the region, providing water for most of the largest water users. The amount of water used for thermoelectric power generation represents by far the largest water demand in the region. In 2010, approximately 2.24 billion gallons per day were withdrawn from surface water bodies for thermoelectric power generation. Over 70 percent of this amount was recirculated water that was withdrawn from and returned to a large cooling reservoir. The remaining 655 million gallons per day (Mgd) was withdrawn from and nearly all returned to the Illinois River.

Roughly 120 of the 210 Mgd withdrawn for all uses other than the thermoelectric sector also comes from the Illinois River, including 87 percent of the self-supplied industrial-commercial water demand (the second-largest water-demand sector) and 18 percent of the public water supply. Of the remainder, other surface water sources provide approximately 23 Mgd and groundwater provides approximately 67 Mgd.

Water demand (excluding thermoelectric use) in the region is mostly concentrated within the two counties with the largest population: Peoria County, which accounts for roughly 72 percent, and LaSalle County, which accounts for roughly 18 percent. A sizeable portion of the demand in Peoria County is associated with the industrial-commercial sector. Water demand for the other counties combined is about 10 percent of the region’s total: Livingston (3.1%), Marshall (2.0%), Putnam (1.6%), Stark (0.4%), and Woodford (2.7%).

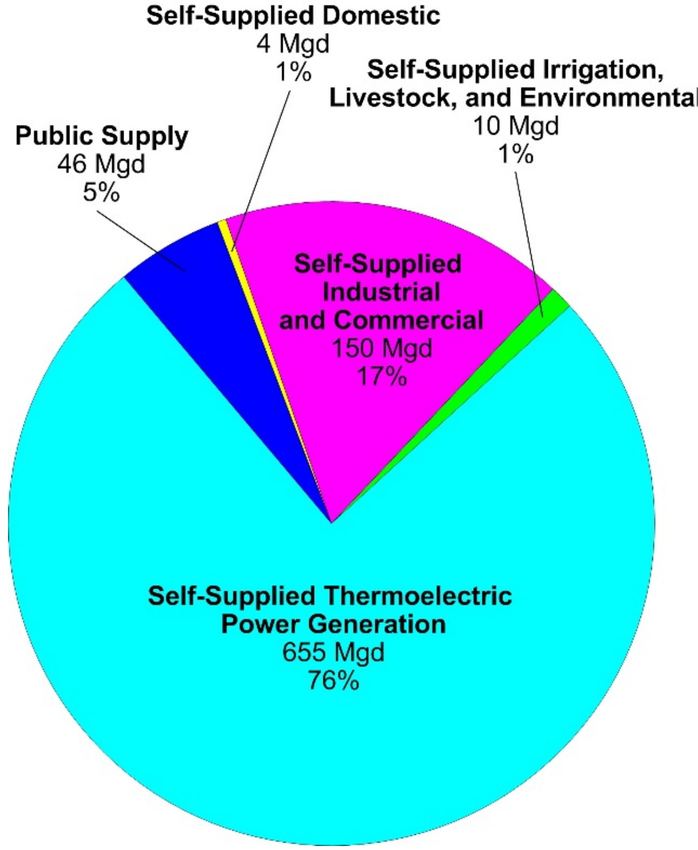


Figure 3. Estimated historical water demand in the Middle Illinois WSPR in 2010

## 2.2 Water Demand Projections: Methodology

Projections of future demand in the Middle Illinois WSPR were developed by the ISWS for the period 2015 to 2060 (Meyer et al., In press). Estimates were developed for all sectors on a county level; estimates of demand for public supply are also developed at a facility level for 24 dominant public systems, representing the largest two to five systems in each county.

The techniques used to develop estimates differ by sector and include unit-demand methods and multiple regressions. These methods provide estimates of future demand as a function of demand drivers and, for many sectors and subsectors, explanatory variables. Explanatory variables are variables influencing unit rates of water demand, such as summer-season temperature and precipitation, median household income, marginal price of water, employment-to-population ratio, labor productivity, and precipitation deficit during the irrigation season. For most sectors and subsectors, we estimated the total demand by multiplying unit rates of water demand by demand drivers. Demand drivers included such measures as population served by public systems, population served by domestic wells, number of employees, gross thermoelectric power generation, irrigated cropland acreage, irrigated golf course acreage, and head counts of various livestock types. Population forecasts out to 2060 for each county and dominant public water system are shown in Tables 1 and 2.

Table 1. Reported and Projected Resident Population (2010-2060)

| County | Estimated Population | Projected Population | | | 2010-2060 Change | 2010-2060 Change (%) |
|---|---|---|---|---|---|---|
| | 2010[1] | 2020[2] | 2040[3] | 2060[3] | | |
| LaSalle | 113,866 | 112,418 | 112,418 | 112,418 | -1,448 | -1 |
| Livingston | 38,853 | 39,391 | 40,432 | 41,520 | 2,667 | 7 |
| Marshall | 12,630 | 11,911 | 11,911 | 11,911 | -719 | -6 |
| Peoria | 186,270 | 188,858 | 193,227 | 197,596 | 11,326 | 6 |
| Putnam | 5,994 | 5,998 | 5,998 | 5,998 | 4 | 0 |
| Stark | 5,967 | 5,585 | 5,585 | 5,585 | -382 | -6 |
| Woodford | 38,640 | 40,350 | 44,269 | 48,165 | 9,525 | 25 |
| **REGIONAL TOTAL** | **402,220** | **404,511** | **413,840** | **423,193** | **20,973** | **5** |

[1]United States Census Bureau (2015)

[2]IDPH projection (Data.Illinois.gov State of Illinois Data Portal, 2015), except for Peoria County estimates, which were developed by Meyer et al. (in press)

[3]See Meyer et al. (in press)

Table 2. Reported and Projected Population Served by Dominant Public Water Supply Systems

| Public Water System | Reported Population Served | Projected Population Served* | | | 2010-2060 Change | 2010-2060 Change (%) |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2040 | 2060 | | |
| **LaSalle County** | | | | | | |
| IL American - Streator | 19,126 | 19,126 | 19,126 | 19,126 | 0 | 0 |
| LaSalle | 9,816 | 9,816 | 9,816 | 9,816 | 0 | 0 |
| Mendota | 7,272 | 7,371 | 7,568 | 7,766 | 494 | 7 |
| Ottawa | 18,700 | 19,081 | 19,844 | 20,606 | 1,906 | 10 |
| Peru | 11,000 | 11,303 | 11,908 | 12,514 | 1,514 | 14 |
| **Livingston County** | | | | | | |
| Chatsworth | 1,300 | 1,300 | 1,300 | 1,300 | 0 | 0 |
| Dwight | 5,448 | 5,448 | 5,448 | 5,448 | 0 | 0 |
| Fairbury | 3,757 | 3,757 | 3,757 | 3,757 | 0 | 0 |
| IL American - Pontiac | 12,000 | 12,080 | 12,241 | 12,401 | 401 | 3 |
| **Marshall County** | | | | | | |
| Henry | 2,580 | 2,580 | 2,580 | 2,580 | 0 | 0 |
| Lacon | 1,983 | 1,983 | 1,983 | 1,983 | 0 | 0 |
| Toluca | 1,388 | 1,401 | 1,427 | 1,453 | 65 | 5 |
| Wenona | 1,121 | 1,121 | 1,121 | 1,121 | 0 | 0 |
| **Peoria County** | | | | | | |
| Chillicothe | 6,000 | 6,085 | 6,256 | 6,427 | 427 | 7 |
| IL American - Peoria | 147,000 | 148,340 | 151,021 | 153,702 | 6,702 | 5 |
| Pleasant Valley PWD | 6,849 | 6,944 | 7,105 | 7,265 | 416 | 6 |
| Princeville | 1,644 | 1,769 | 2,020 | 2,271 | 627 | 38 |
| **Putnam County** | | | | | | |
| Granville | 2,020 | 2,020 | 2,020 | 2,020 | 0 | 0 |
| Hennepin PWD | 750 | 760 | 779 | 798 | 48 | 6 |
| Mark | 491 | 518 | 571 | 625 | 134 | 27 |
| **Stark County** | | | | | | |
| Toulon | 1,356 | 1,356 | 1,356 | 1,356 | 0 | 0 |
| Wyoming | 1,509 | 1,509 | 1,509 | 1,509 | 0 | 0 |
| **Woodford County** | | | | | | |
| Eureka | 5,420 | 5,821 | 6,622 | 7,424 | 2,004 | 37 |
| Goodfield | 700 | 843 | 1,128 | 1,414 | 714 | 102 |
| **REGIONAL TOTAL** | **269,230** | **272,332** | **278,507** | **284,682** | **15,452** | **6** |

*Projections for the systems are estimates based on historical trends and Illinois Department of Public Health population projections (Meyer et al., In press)

We employed available data and analysis to estimate plausible future values of demand drivers, explanatory variables, and unit rates of water demand. For each sector, we developed three scenarios of future water demand that reflect three different sets of plausible socioeconomic and weather conditions: a current trends (CT) (baseline) scenario, a less resource intensive (LRI) scenario, and a more resource intensive (MRI) scenario. To estimate water demand under each scenario, we used different sets of justifiable assumptions regarding future values of explanatory variables, unit rates of water demand, and/or demand drivers. A "normal" climate, based on 1981-2010 climate "normals," was assumed in all scenarios. Although our estimates suggested a plausible range of future demand, they do not represent forecasts or predictions, and they do not indicate upper and lower bounds of future water demand. Different assumptions or different future conditions could result in predicted or actual water demand that is outside of this range.

We employed data from a diversity of sources to estimate future values of demand drivers, explanatory variables, unit rates of water demand, and—ultimately—total water demand. Facility-level historical water withdrawal data were obtained from the ISWS IWIP database. We also used county-level demand data developed by the United States Geological Survey (USGS), which in turn bases its estimates for many sectors on IWIP data. Counts of domestic wells were obtained from a database maintained by the ISWS. We obtained data on historical and future values of demand drivers and explanatory variables from state and federal agencies, including the Illinois Commerce Commission; Illinois Department of Employment Security; Illinois Department of Public Health; Illinois Environmental Protection Agency; Midwestern Regional Climate Center, Center for Atmospheric Science, ISWS; United States Census Bureau; United States Department of Agriculture; United States Department of Labor Bureau of Labor Statistics; and the United States Energy Information Administration.

## 2.3 Water Demand Projections: Results

### *2.3.1 Self-Supplied Water for Thermoelectric Power Generation*

Demand for self-supplied water for thermoelectric power generation—i.e., for power plants fueled by nuclear fission or fossil fuels—dominates water demand in the region (Figure 3). We discuss this sector in greater detail than the other sectors, partly because of its dominance of regional water demand, but also because the fate of the water used in thermoelectric power generation is critically important in understanding its impacts, and because future demand for self-supplied water for thermoelectric power generation is particularly challenging to quantify.

Water for thermoelectric power generation is used almost entirely for cooling, and, because the demand for cooling water at power plants is great, most plants are sited adjacent to large rivers, lakes, or reservoirs. Cooling system design, as well as gross generation capacity, strongly influence water demand. Two categories of cooling processes are employed: (1) once-through and (2) closed-loop cooling. Once-through cooling water is typically withdrawn from a large river and virtually all of the water is immediately returned to its source of supply, usually a short distance downstream of the withdrawal location, albeit at a higher temperature. Closed-loop cooling involves recirculation of water, during which water is cooled either through a large cooling pond, evaporative cooling towers, or heat exchangers at the power plant.

Power plants in the Middle Illinois WSPR that use once-through cooling exclusively use the Illinois River as their source of supply. Water is returned at a higher temperature than the ambient temperature in the river, which results in additional (forced) evaporation from the river.

An estimated less than 3 percent of the water withdrawn at plants using once-through cooling is typically consumed, mainly through forced evaporation (Solley et al., 1998).

Most large, traditional power plants using closed-loop cooling have a large cooling lake through which water is recirculated (withdrawn and returned). The returned water is at a higher temperature, which causes evaporation from the lake, typically resulting in a loss of 2 to 3 percent of the total amount of circulated water. A separate source of make-up water is needed to replace that lost through evaporation. Also, some of the recirculated water is extracted from the system and discharged as effluent as a way to remove hardness and chemicals that build up during recirculation. This effluent, often called blow-down, is typically discharged downstream from the source of the make-up water. A more modern type of closed-loop cooling system involves evaporative cooling towers, which intakes less water but consumes most of the water used.

Water demand by power plants using once-through cooling is typically greater per unit of generated electricity than by plants using closed-loop cooling. However, the proportion of the withdrawn water lost to evaporation or consumed is greater from plants using closed-loop systems. Closed-loop systems with cooling towers, for example, can lose from 30 percent in nuclear facilities to 70 percent in plants using fossil fuels (Dziegielewski and Bik, 2006).

Three thermoelectric power-generating plants are located in the Middle Illinois WSPR. Two (Ameren-Edwards and Dynegy-Hennepin) use once-through cooling. The third and largest (Exelon-LaSalle), accounting for more than 70 percent of the electricity generated in the WSPR, uses a cooling lake. The amount of water recirculated from the cooling lake is nearly 1.6 billion gallons per day, more than 70 percent of the total amount of water withdrawn in the WSPR. For the remainder of this report, we have ignored the recirculated water from this plant and only considered the amounts of make-up and blow-down water that are withdrawn and discharged to the Illinois River. With this omission, the total amount of water withdrawn for the region's thermoelectric power generation was 655 Mgd in 2010 (as shown in Figure 3).

The difference between the amount of water withdrawn and water returned to the source (or discharge) is usually taken to represent consumptive use. The amount of water consumed by power plants can be difficult to calculate. Torcellini et al. (2003) calculated the average consumptive loss (by evaporation) in Illinois to be 1.05 gallons per kilowatt-hour (KWh) of generated energy. However, this amount varies considerably depending on the cooling process. As mentioned before, the loss at once-through cooling plants is estimated to be 3 percent or less of the withdrawn amount, which corresponds to 17.5 Mgd collectively for the two once-through plants in the WSPR in 2010. For the largest closed-loop power plant, the amount of consumed water can be calculated directly as the difference between the average rates of its make-up water (74 Mgd) and blow-down water (48 Mgd), or roughly 26 Mgd as calculated using data provided by IWIP and the Illinois Environmental Protection Agency (IEPA). Although there are other factors to consider in the closed-loop calculation, including the precipitation to and ambient evaporation from the cooling lake, the net differences of these factors are expected to be 3 Mgd or less. The collective consumptive loss for all three power plants is thus estimated to be between 40 and 44 Mgd.

Future demand for self-supplied water for thermoelectric power generation in the Middle Illinois WSPR depends heavily on the gross generating capacity and the cooling system design of active power plants in the region. An estimation of this demand cannot be based on local demand for electricity, because electricity that is generated in the region may be sold outside the region. In fact, assuming an Illinois Commerce Commission estimate of per-capita electricity demand of 10.14 megawatt hours per capita-year (MWh/capita-year), we estimated that regional electricity demand in 2010 was only about 15 percent of gross generation in the Middle Illinois WSPR. In 2016, the smallest (80 megawatts [MW]) production unit at the Ameren-Edwards power plant was retired, which resulted in a reduction in withdrawals from the Illinois River from 655 Mgd to 588 Mgd. The demand scenarios assume no expansion of thermoelectric generation in the region through 2060.

### *2.3.2 Self-Supplied Water for Industrial-Commercial Uses*

Waters withdrawn for self-supplied industrial and commercial (IC) uses are the second largest sector of water use in the Middle Illinois WSPR. The region's IC water use in 2010 was 150 Mgd (Table 3). The Illinois River provides the greatest source of supply, accounting for 112 of the 150 Mgd, with groundwater sources providing 19 Mgd and other surface water bodies also providing 19 Mgd. Figure 4 shows the distribution by county of water withdrawals in the region for non-mining IC uses. The greatest concentration of IC water use, nearly 133 Mgd (98 percent of the region's total), is in Peoria County. A single large facility alone accounts for 120 Mgd (88 percent). As with many large industries, a large portion of the self-supplied water use for this facility is once-through non-contact cooling water that is immediately thereafter returned to the Illinois River.

A second concentration of IC water use in the region is for sand and gravel mining in LaSalle County (Figure 5). The 2010 mining use in LaSalle County was 16 Mgd, approximately 11 percent of the region's total IC use. Since 2010, LaSalle County's water use for sand and gravel mining has increased to more than 20 Mgd. Nearly all of the mining water uses are categorized as surface water withdrawals, which are removed from ponds within the sand and gravel quarries. However, in practical terms, the water taken from these quarries is essentially a very large groundwater withdrawal from the local sandstone aquifer because most water enters the quarry pits by way of groundwater inflow. Roughly half of the mining water used in LaSalle County is discharged to the Illinois and Michigan Canal, which then discharges into the Illinois River. At most other quarries, the pumped water is typically discharged to other locations in the quarry and effectively becomes part of a closed-loop recirculation system in which relatively little water is lost from the quarry.

The main driver of future self-supplied IC demand is assumed to be the future output of goods and services, which is a function of total employment and labor productivity. According to projections provided by the Illinois Department of Employment Security (2014), total employment in Illinois is projected to increase by 7 percent between 2010 and 2020. For this study, we reduced the 2010-2020 annual growth rate by 30 percent and 50 percent for the periods 2021-2040 and 2041-2060, respectively. The following three scenarios of future IC demand adopted for this study reflect the three different sets of plausible socioeconomic conditions:

- The current trends (CT) scenario assumes that labor productivity increases by 0.8 percent per year and water conservation measures reduced water demands by 0.40 percent per year.
- The less resource intensive (LRI) scenario assumes that labor productivity increases by 0.6 percent per year and water conservation reduces water demands by 0.8 percent per year.
- The more resource intensive (MRI) scenario assumes that labor productivity increases by 1.0 percent per year and there are no new water conservation efforts.

Table 4 shows the projected regional increase in water demand under these three scenarios. The scenarios assume that no new water-intensive industries (e.g., biodiesel or ethanol plants) locate within the region by 2060. Greater detail about these projections is given in Meyer et al. (In press).

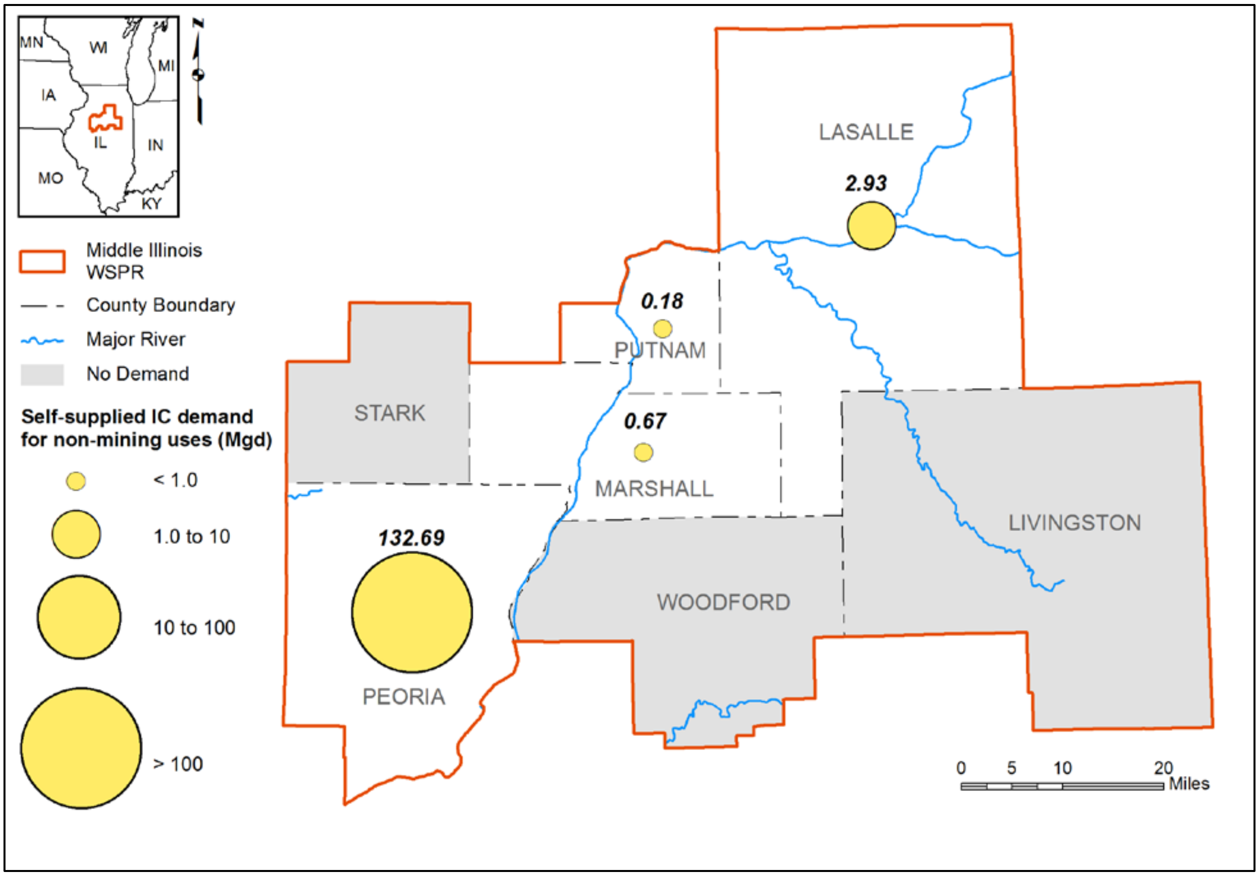


Figure 4. Self-supplied IC demand (Mgd) in 2010 for non-mining uses by county (United States Geological Survey, 2014)

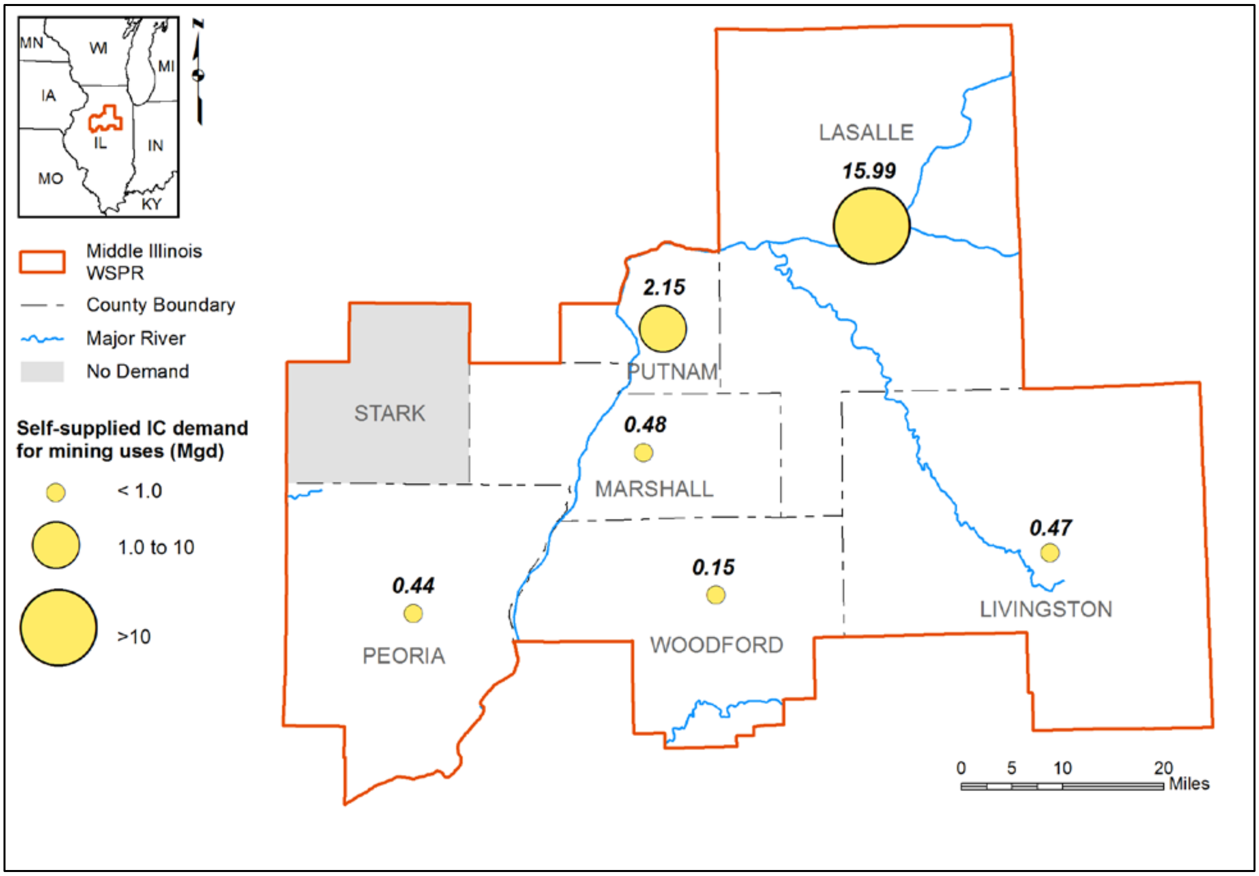


Figure 5. Self-supplied IC demand (Mgd) in 2010 for mining uses by county (United States Geological Survey, 2014)

Table 3. County IC Water Demand, Self-Supplied and Purchased (2010)

| County | Self-Supplied (Mgd) | Purchased (Mgd) | Percent Self-Supplied |
|---|---|---|---|
| LaSalle | 18.92 | 2.32 | 89.1 |
| Livingston | 0.47 | 2.98 | 13.6 |
| Marshall | 1.15 | 0.86 | 57.2 |
| Peoria | 126.99 | 10.44 | 92.4 |
| Putnam | 2.33 | 0.09 | 96.3 |
| Stark | 0.00 | 0.26 | 0.0 |
| Woodford | 0.15 | 0.27 | 35.7 |
| **REGIONAL TOTAL** | **150.01** | **17.22** | **89.7** |

Data from (United States Geological Survey, 2014)

Table 4. Self-Supplied Industrial-Commercial Water Demand Scenarios

| Year | Demand (Mgd) | | |
|---|---|---|---|
| | **CT (Baseline) Scenario** | **LRI Scenario** | **MRI Scenario** |
| 2010 (Reported)[1] | 150.01 | 150.01 | 150.01 |
| 2015 | 163.43 | 158.61 | 168.37 |
| 2020 | 178.09 | 167.73 | 189.03 |
| 2025 | 182.83 | 167.11 | 199.92 |
| 2030 | 191.58 | 169.94 | 215.82 |
| 2035 | 200.53 | 172.62 | 232.74 |
| 2040 | 209.81 | 175.28 | 250.87 |
| 2045 | 219.43 | 177.91 | 270.32 |
| 2050 | 229.41 | 180.50 | 291.15 |
| 2055 | 239.75 | 183.07 | 313.47 |
| 2060 | 250.46 | 185.60 | 337.38 |
| **2010 (Reported)-2060 Change** | **100.45** | **35.59** | **187.37** |
| **2010 (Reported)-2060 Change (%)** | **67.0** | **23.7** | **124.9** |

[1]United States Geological Survey (2014)

### *2.3.3 Public Water Systems*

Approximately 46 Mgd of water was withdrawn in 2010 for communities and other public water systems in the WSPR (Figure 3). The 24 dominant systems designated in the demand study (Meyer et al., In press) are shown in Figure 6, and 2010 populations served and water demands are shown in Table 5. Public water use in Peoria County accounts for half the amount used in the region (nearly 24 Mgd), since the Illinois American Water system in Peoria is the largest system with an average daily use of more than 20 Mgd. The distribution of public water use in the region mostly corresponds to the distribution of population. However, more than one-third of the water treated for public water use is sold to industrial and commercial interests; approximately 17 Mgd was purchased by industrial and commercial interests in the region in 2010, concentrated in Peoria County.

Only three public water systems in the region use surface water for their supply: Peoria, Streator, and Pontiac. All three systems are operated by the Illinois American Water Company (IAWC). Streator and Pontiac both obtain their primary water supply from the Vermilion River and have off-channel storage reservoirs that are used when the river's quality and quantity are insufficient to meet the communities' needs. The Peoria system blends surface water from the Illinois River with groundwater, the latter obtained from shallow sand and gravel deposits along the Illinois River. Groundwater sources typically provide about 60 percent of Peoria's water. The remaining public systems in the region obtain their water from groundwater sources. In general, communities located along the Illinois River obtain their water from shallow aquifers (Peru and Ottawa are two primary exceptions), and communities located away from the river use deeper bedrock aquifers.

Projected regional changes in water demand for the three scenarios (CT, LRI, MRI) are shown in Table 6. Greater detail about these projections is given in (Meyer et al., In press).

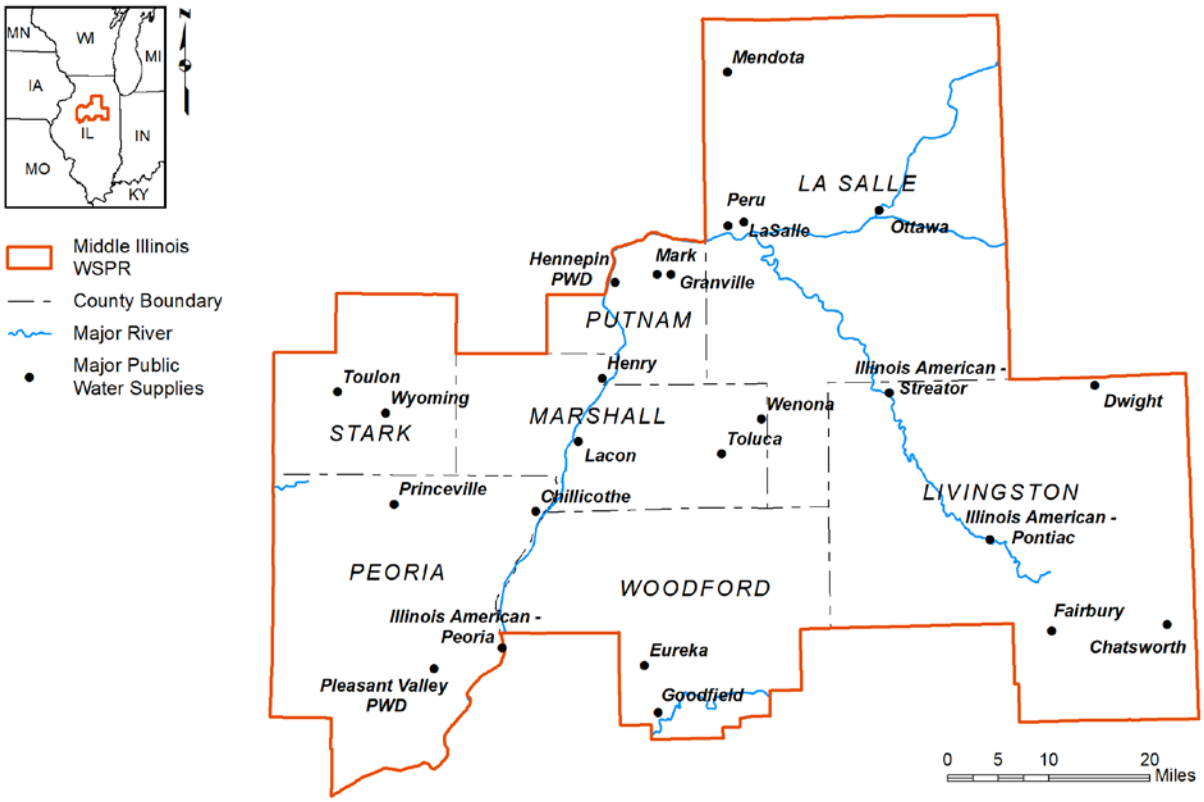


Figure 6. The 24 dominant public water systems designated by (Meyer et al., In press)

Table 5. Population Served and Water Use in 2010 for Public Water Supplies in the Middle Illinois Region

| Facility | Population Served | Water Use (Mgd) |
|---|---|---|
| **LaSalle County** | | |
| IL American - Streator | 19,126 | 1.983 |
| LaSalle | 9,816 | 3.141 |
| Mendota | 7,272 | 1.104 |
| Ottawa | 18,700 | 2.437 |
| Peru | 11,000 | 2.888 |
| LaSalle County Residual[1] | 31,593 | 2.664 |
| **Livingston County** | | |
| Chatsworth | 1,300 | 0.117 |
| Dwight | 5,448 | 0.493 |
| Fairbury | 3,757 | 0.419 |
| IL American - Pontiac | 12,000 | 1.776 |
| Livingston County Residual | 6,004 | 0.654 |
| **Marshall County** | | |
| Henry | 2,580 | 0.415 |
| Lacon | 1,983 | 0.470 |
| Toluca | 1,388 | 0.338 |
| Wenona | 1,121 | 0.169 |
| Marshall County Residual | 2,698 | 0.202 |
| **Peoria County** | | |
| Chillicothe | 6,000 | 0.946 |
| IL American - Peoria | 147,000 | 20.290 |
| Pleasant Valley PWD | 6,849 | 0.378 |
| Princeville | 1,644 | 0.317 |
| Peoria County Residual | 22,379 | 2.040 |
| **Putnam County** | | |
| Granville | 2,020 | 0.115 |
| Hennepin PWD | 750 | 0.119 |
| Mark | 491 | 0.074 |
| Putnam County Residual | 1,560 | 0.145 |
| **Stark County** | | |
| Toulon | 1,356 | 0.152 |
| Wyoming | 1,509 | 0.289 |
| Stark County Residual | 750 | 0.098 |
| **Woodford County** | | |
| Eureka | 5,420 | 0.655 |
| Goodfield | 700 | 0.081 |
| Woodford County Residual | 18,024 | 1.870 |
| **REGIONAL TOTAL** | **352,238** | **46.839** |

[1]Residuals are a sum of all public water supply facilities in a county not specified in the table.

Table 6. Public Water Supplies Water Demand Scenarios

| Year | Demand (Mgd) | | |
|---|---|---|---|
| | CT (Baseline) Scenario | LRI Scenario | MRI Scenario |
| 2010 (Reported) | 46.39 | 46.39 | 46.39 |
| 2015 | 47.44 | 44.64 | 50.40 |
| 2020 | 47.09 | 43.43 | 51.01 |
| 2025 | 46.80 | 42.31 | 51.70 |
| 2030 | 46.52 | 41.23 | 52.39 |
| 2035 | 46.23 | 40.17 | 53.09 |
| 2040 | 45.95 | 39.13 | 53.80 |
| 2045 | 45.67 | 38.12 | 54.51 |
| 2050 | 45.38 | 37.14 | 55.23 |
| 2055 | 45.10 | 36.18 | 55.96 |
| 2060 | 44.82 | 35.24 | 56.70 |
| **2010 (Reported)-2060 Change** | **-0.92** | **-10.49** | **10.96** |
| **2010 (Reported)-2060 Change (%)** | **-2.0** | **-22.9** | **24.0** |

### *2.3.4 Other Water Demand Sectors*

Self-supplied irrigation, livestock, and environmental (ILE) demand totaled 10 Mgd in 2010, or 1 percent of regional demand, and self-supplied domestic demand totaled 4 Mgd, less than 1 percent of regional demand. Environmental uses within the ILE sector include water used to support environmental amenities such as wetlands, forest and prairie preserves, park districts, and game farms. Under the CT scenario, ILE demands are projected to increase from 13.65 Mgd in 2010 to 20.65 Mgd in 2060. For the LRI and MRI scenarios, the increases were to 17.00 Mgd and 26.59 Mgd, respectively. Increased demand was a result of increases in irrigated cropland acreage.

### *2.3.5 Summary of Water Demand Scenarios in the Middle Illinois WSPR*

Figure 7 shows aggregate projected demand in the Middle Illinois WSPR to 2060 for all sectors except self-supplied thermoelectric power generation. From 2010 to 2060, total demand in the region is projected to increase to 241 Mgd under the LRI scenario, 320 Mgd under the CT scenario, and 425 Mgd under the MRI scenario. Use of a climate-normalized estimate of 2010 demand—one in which we used the methods of this study to estimate public supply and ILE demand under 1981-2010 normal climate—permits meaningful comparison of future-demand estimates with present demand, as represented by 2010 socioeconomic conditions. We estimated the 2010 climate-normalized demand at 213 Mgd, which is slightly higher than the reported total of 210 Mgd. Our 2060 LRI, CT, and MRI totals are, respectively, 13 percent, 50 percent, and 99 percent greater than the 2010 climate-normalized total. Figures 8, 9, and 10 show climate-normalized demand for each sector (omitting thermoelectric power generation) under each scenario. The figures show that most of the increase in total demand under all scenarios, particularly the CT and MRI scenarios, is accounted for by increases in self-supplied IC demand.

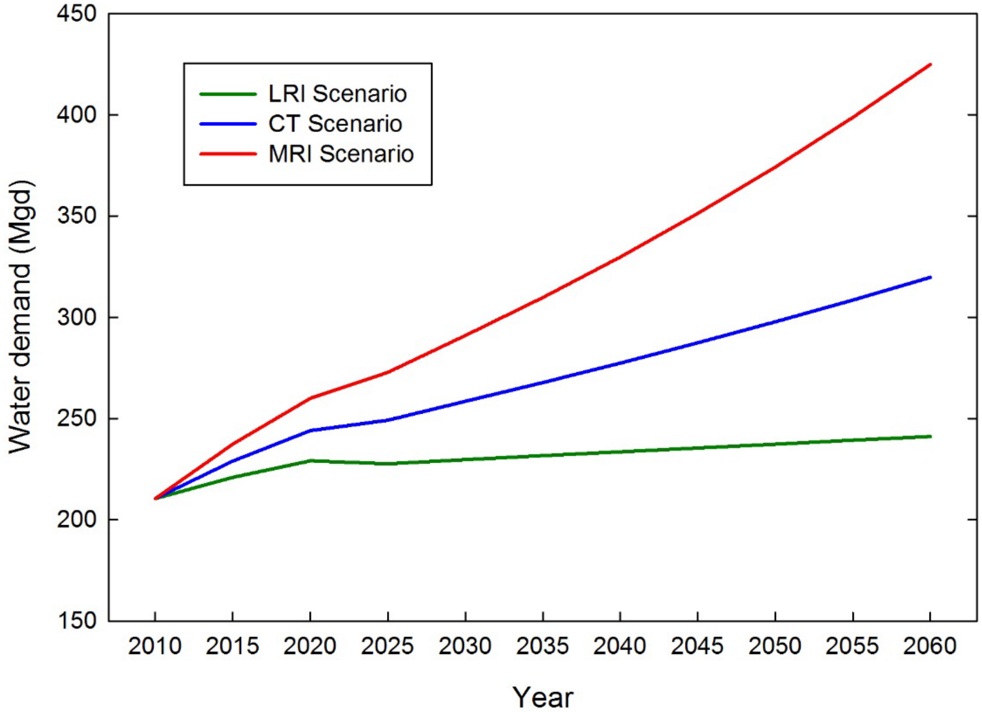


Figure 7. Projected (2015-2060) water demand in the Middle Illinois WSPR for all demand sectors except self-supplied thermoelectric power generation

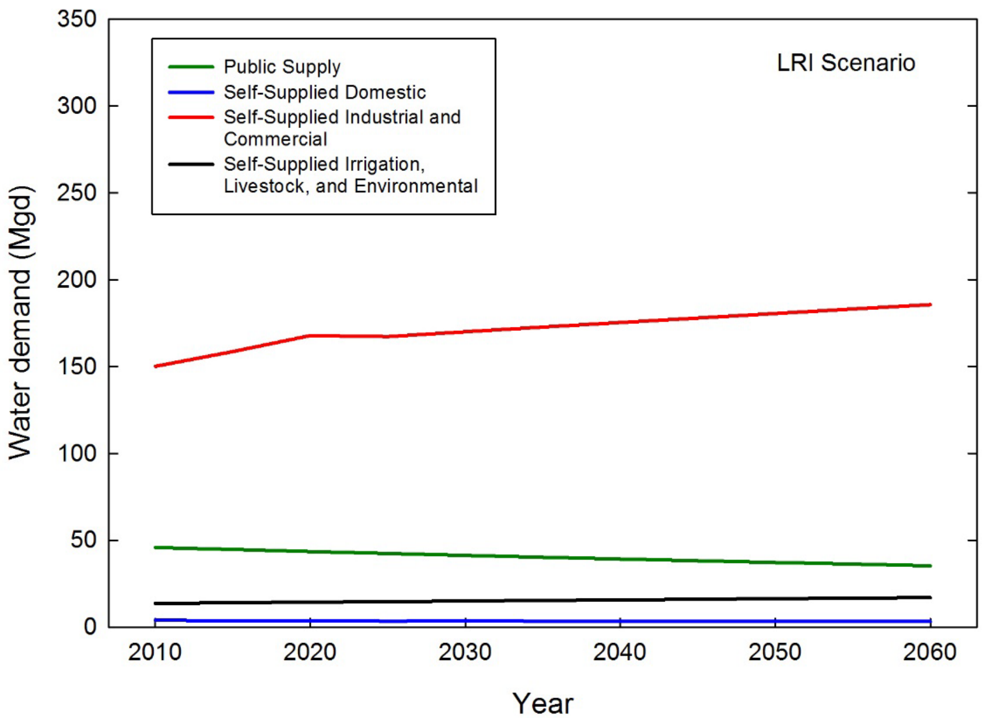


Figure 8. Climate-normalized historical (2010) and projected (2015-2060) water demand in the Middle Illinois WSPR for all demand sectors except self-supplied thermoelectric power generation, LRI scenario

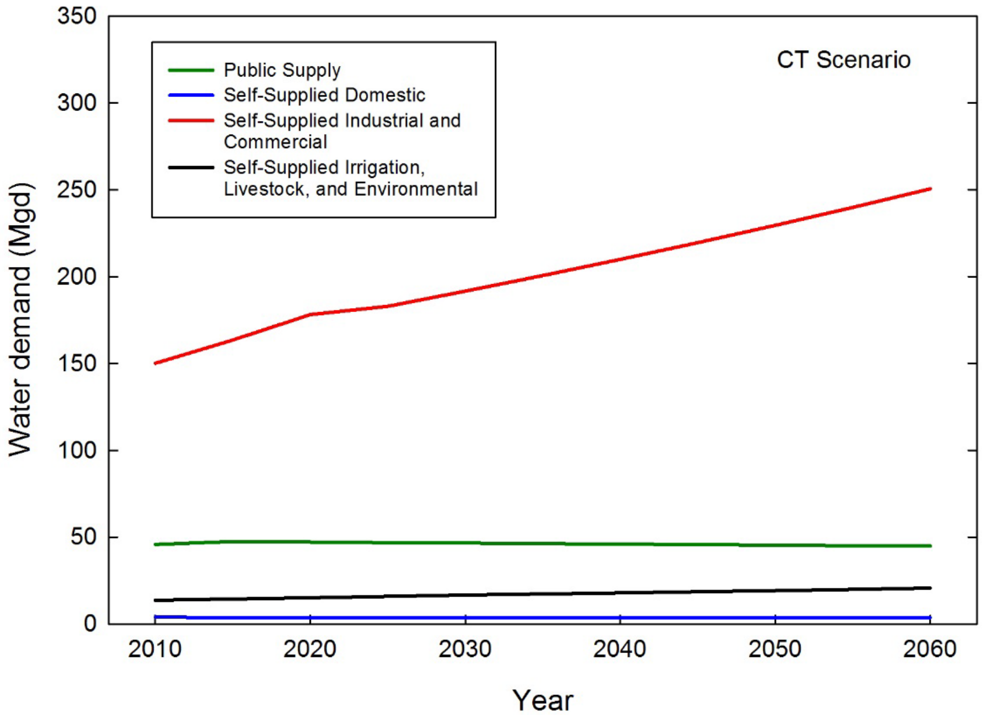


Figure 9. Climate-normalized historical (2010) and projected (2015-2060) water demand in the Middle Illinois WSPR for all demand sectors except self-supplied thermoelectric power generation, CT scenario

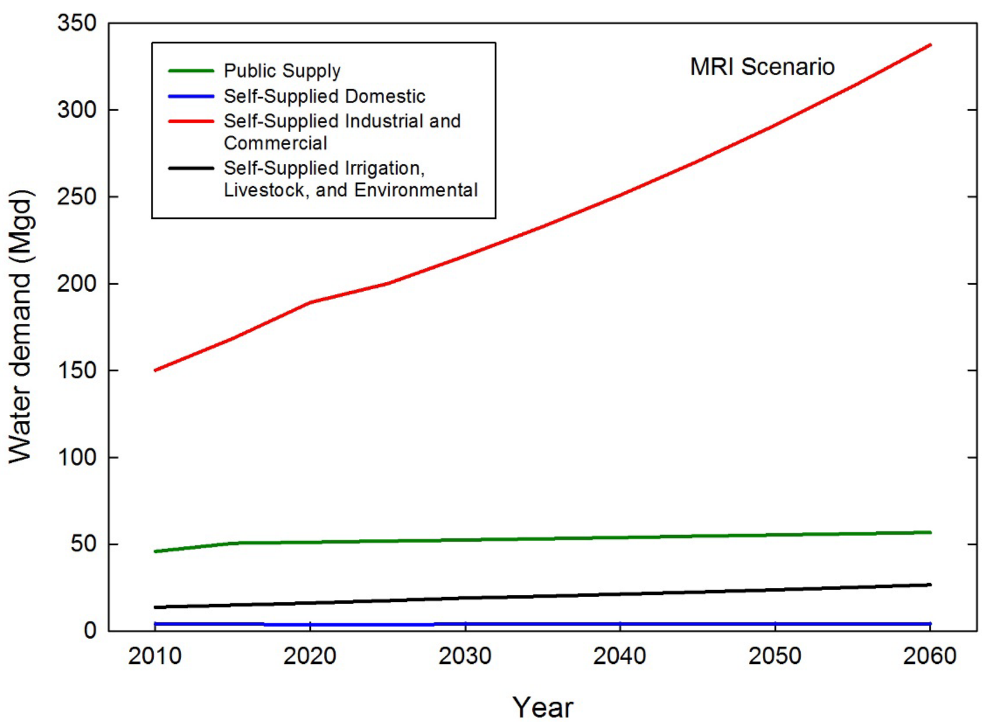


Figure 10. Climate-normalized historical (2010) and projected (2015-2060) water demand in the Middle Illinois WSPR for all demand sectors except self-supplied thermoelectric power generation, MRI scenario

# 3 Groundwater Studies in Middle Illinois

## 3.1 Aquifers of Illinois

Illinois has three classes of productive aquifers: (1) sandstone; (2) weathered carbonate; and (3) coarse-grained unconsolidated (sand and gravel) aquifers.

1. Sandstone is a sedimentary rock with comparatively large pore spaces between grains, at least in Illinois. Furthermore, the pore spaces are generally interconnected, resulting in a high enough permeability for use as an aquifer. Permeability is a measure of the ease with which water can move through a material. Sandstones in the Middle Illinois WSPR are mostly Cambrian or Ordovician in age, collectively referred to as ***Cambrian-Ordovician sandstone aquifers***.
2. Carbonate rocks (limestone and dolomite) can also be aquifers in Illinois, particularly where they are within 125 feet of the bedrock surface. In Illinois, carbonates are more susceptible to weathering than other rock types (e.g., sandstone and shale). This weathering results in the development of secondary porosity in the form of solution-enlarged fractures, cracks, and crevices. As a result, highly productive weathered aquifers in Illinois are generally referred to as ***shallow carbonate bedrock aquifers***.
3. Bedrock in the Middle Illinois WSPR is generally covered with unconsolidated deposits, except for very localized areas along the Illinois River in LaSalle County where unconsolidated materials are absent. ***Coarse-grained unconsolidated aquifers*** form where these deposits are generally composed of sand and gravel, common along rivers or in bedrock valleys. Sand and gravel aquifers generally have higher permeability and shallower water levels than most bedrock aquifers, which make them more economical to develop. However, shallow aquifers are often more susceptible to contamination, particularly if sand and gravel is at or near the land surface.

Many major aquifers in Illinois are contained within sequences of high- and low-permeability layers. These low-permeable layers are known as aquitards. In the presence of aquitards, the exchange of groundwater between aquifers is minimal. In Illinois, bedrock layers not composed of sandstone or weathered carbonates serve as aquitards. Fine-grained clays and silts within unconsolidated glacial material also act as aquitards and drastically limit recharge.

When aquifers that are overlain by aquitards are completely saturated, they are referred to as confined. Groundwater within confined aquifers is under pressure. Water in a well open to the confined aquifer rises to a level that represents this pressure; this water level is referred to as the head. In a confined aquifer, the head is by definition above the top of the aquifer. Eventually, if withdrawals from a confined aquifer are great enough, the head may fall below the top of the aquifer, causing the aquifer to become unconfined. The upper boundary of an unconfined aquifer is not an aquitard, but is defined by the head in the aquifer (Freeze and Cherry, 1979). Unconfined aquifers can also occur naturally where overlying aquitards are not present, such as the outwash aquifers along major river corridors. In an unconfined aquifer, additional groundwater withdrawals beyond ambient groundwater flow are supplied by drainage of water from the pore spaces in the aquifer.

## 3.2 Geologic Overview

The geologic relationships and characteristics of geologic materials control the hydrologic framework. In general, the geologic framework of the Middle Illinois WSPR is associated with (a) sedimentary rocks within the Illinois Basin and (b) the overlying unconsolidated deposits of the latest glacial episodes in Illinois.

The regional bedrock geologic feature that controls broad stratigraphic relationships in the region is the Illinois Basin, which formed from structural subsidence and subsequent infilling with sedimentary rocks. Rocks in the Illinois Basin are Paleozoic in age (540-290 million years ago [Mya]), overlie older Precambrian rocks (> 540 Mya), and are composed of sequences of carbonate, shale, and sandstone rocks (Figures 11 and 12). These rocks range in thickness from around 2,000 feet in northern Illinois to over 20,000 feet in southern Illinois. Greater than 50 percent of the sedimentary rocks are carbonate, approximately 25 percent are sandstone, and the remainder is shale, siltstone, and coal (Buschbach and Kolata, 1991). In the Middle Illinois WSPR, most of the rocks at the top of the Illinois Basin are Pennsylvanian in age (290-320 Mya) (Figure 12), and they are composed largely of shale, limestone, coal, and some thin sandstone rocks. In the northern part of the Middle Illinois WSPR, Cambrian and Ordovician rocks (540-440 Mya) are at the top of the Illinois Basin. In this area, these rocks are at the top of the stratigraphic sequence because of their upward movement along the Sandwich Fault Zone (Figure 12). These rocks are largely made up of sandstone and are often exposed at the land surface near the Illinois and Fox River Valleys.

Regional glacial events (< 2 Mya) buried most of the Paleozoic rocks of the Illinois Basin with relatively thin, unconsolidated sediments composed of clay, silt, and sand and gravel (Figure 8). The vast majority of glacial sediments in the study area were deposited during the last two glacial episodes, the Illinois (~120,000 years ago) and Wisconsin (~40,000-10,000 years ago) Episodes. In contrast to bedrock stratigraphy, the distribution and occurrence of glacial sediments is much more variable, even at the scale of a few miles. These sediments may be consistently 200-400 feet thick along *moraines*, which are landforms derived when glaciers deposited sediments along their margins for long periods. Alternatively, sediments may be absent in areas where post-glacial erosion has removed them. In the Middle Illinois WSPR, moraine deposits, which are most often made up of fine-grained sediments, are located along the eastern edge of the Illinois River valley and across regions of LaSalle and Livingston Counties. Within the Illinois River valley, sediments are often composed largely of coarse-grained fluvial sand and/or gravel derived from post-glacial outwash streams or modern stream processes. These sediments may be absent (e.g., some locations in LaSalle County) or up to 100 feet thick (e.g., northern Peoria County). Significant sand and gravel deposits may be present throughout the Middle Illinois WSPR, but they are buried beneath younger clay-rich sediments and moraine landforms. For example, sand and gravel deposits associated with an ancient Mississippi River Valley (Berg et al., 2015) may be as much as 200 feet thick, but they are buried at a depth of over 200 feet throughout eastern Putnam, Marshall, and Woodford Counties. Other significant sand and gravel deposits of glacial origin are found within buried valleys that eroded into the bedrock surface in parts of LaSalle and Putnam Counties.

## 3.3 Hydrostratigraphic Units of Middle Illinois

To conceptualize groundwater flow in the state, the ISWS has combined adjacent geologic strata with similar hydrologic characteristics into individual hydrostratigraphic units. Thirteen hydrostratigraphic units are present in the Middle Illinois WSPR (Table 7). Each unit is assigned a generalized geologic material (sand and gravel, silt and clay, carbonate, sandstone, shale, or crystalline) based on available geologic information and insight from calibrated groundwater flow models (Abrams et al., In press, Roadcap et al., 2013). The generalized geologic material of each hydrostratigraphic unit reflects its regional effect on groundwater flow. However, other geologic materials are frequently present and may affect groundwater flow on a local scale (Abrams et al., In press, Roadcap et al., 2013). The generalized geologic material of each hydrostratigraphic unit reflects its regional effect on groundwater flow. However, other geologic materials are frequently present and may affect groundwater flow on a local scale.

Unconsolidated glacial materials are subdivided into two basic hydrostratigraphic units, fine- and coarse-grained Quaternary (Table 7); however, these units often occur in a complicated sequence of layers as a result of multiple glacial advances and river deposits. In areas along the Illinois River where detailed mapping of Quaternary deposits has been done, these hydrostratigraphic units are subdivided into named Quaternary layers (see McKay et al. (2010) and related ISGS geologic maps). Such detailed mapping has not been conducted in most of the Middle Illinois WSPR away from the Illinois River where thick sand and gravel deposits are uncommon. Furthermore, the mapping that has been done has not been digitized into a format that can be added into the existing groundwater flow model.

To depict the unconsolidated material for modeling, the material between the land and bedrock surfaces was divided into nine layers of equal thickness, gridded to the same 625 foot cell size as other geologic base data in Illinois (Abrams et al., In press). The layers were then assigned a percent thickness of coarse-grained material as determined by a database query of existing well logs. Two zones were then spatially distributed over each layer, the first representing sand extending over at least 25 percent of the thickness of the layer (coarse grained) and the second representing minimal sand (fine grained). The resulting nine-layer conceptualization of unconsolidated materials depicts Quaternary glacial deposits, such as the Sankoty Sand, as well as younger sand and gravel outwash aquifers (Figure 11). This depiction of unconsolidated materials is approximate and sufficient for regional analyses and first-order assessments of groundwater conditions. However, this approach may require further refinements of the geology on a local scale, particularly in areas with large demands from the unconsolidated aquifers, such as Peoria.

The remaining 11 hydrostratigraphic units represent bedrock material (Figure 12). Maps depicting the top elevation of each bedrock hydrostratigraphic unit have been completed for the northern half of Illinois, as well as southern Wisconsin and Indiana (Abrams et al., In press). Several bedrock hydrostratigraphic units are at the bedrock surface in Illinois (Figure 13); these units are often weathered and can serve as productive aquifers. However, in most of the Middle Illinois WSPR the Pennsylvanian-Mississippian Unit is at the bedrock surface. Although this unit can contain thin layers of limestone and sandstone, it is predominantly shale, which typically has low permeability and hence does not generally form an aquifer. As a result, communities in the southern portion of the Middle Illinois WSPR must use deeper units to obtain an economically efficient supply of groundwater. Only in northern LaSalle County are predominantly non-shale materials located at or near the bedrock surface.

Table 7. Geologic Composition of the Hydrostratigraphic Units Present in the Study Region

<table>
<tr><th>AGE (SYSTEM OR SERIES)</th><th colspan="2">STRATIGRAPHY</th><th>HYDROSTRATIGRAPHIC UNIT</th><th>GENERALIZED GEOLOGIC MATERIAL</th></tr>
<tr><td rowspan="2">QUATERNARY</td><td colspan="2" rowspan="2">Unconsolidated</td><td>Coarse-Grained Quaternary</td><td>25-100% of the layer represents sand and gravel</td></tr>
<tr><td>Fine-grained Quaternary</td><td>Less than 25% of the layer represents sand and gravel</td></tr>
<tr><td>CRETACEOUS</td><td colspan="2" rowspan="4">Lithostratigraphic units not detailed</td><td rowspan="4">Pennsylvanian-Mississippian</td><td rowspan="4">Shale</td></tr>
<tr><td>PENNSYLVANIAN</td></tr>
<tr><td>MISSISSIPPIAN</td></tr>
<tr><td>UPPER DEVONIAN</td></tr>
<tr><td>MIDDLE DEVONIAN</td><td colspan="2" rowspan="3">Lithostratigraphic units not detailed</td><td rowspan="3">Silurian-Devonian</td><td rowspan="3">Carbonate</td></tr>
<tr><td>LOWER DEVONIAN</td></tr>
<tr><td>SILURIAN</td></tr>
<tr><td rowspan="6">ORDOVICIAN</td><td colspan="2">Maquoketa Group</td><td>Maquoketa</td><td>Shale</td></tr>
<tr><td colspan="2">Galena Group</td><td rowspan="2">Galena-Platteville</td><td rowspan="2">Carbonate</td></tr>
<tr><td colspan="2">Platteville Group</td></tr>
<tr><td rowspan="2">Ancell Group</td><td>Glenwood Formation</td><td rowspan="2">St. Peter</td><td rowspan="2">Sandstone</td></tr>
<tr><td>St. Peter Sandstone</td></tr>
<tr><td colspan="2">Prairie du Chien Group</td><td rowspan="2">Prairie du Chien-Eminence</td><td rowspan="2">Carbonate</td></tr>
<tr><td rowspan="9">CAMBRIAN</td><td colspan="2">Jordan Formation (only northwestern Illinois), Eminence Formation</td></tr>
<tr><td colspan="2">Potosi Dolomite</td><td rowspan="2">Potosi-Franconia</td><td rowspan="2">Carbonate</td></tr>
<tr><td colspan="2">Franconia Formation</td></tr>
<tr><td colspan="2">Ironton Formation</td><td rowspan="2">Ironton-Galesville</td><td rowspan="2">Sandstone</td></tr>
<tr><td colspan="2">Galesville Formation</td></tr>
<tr><td rowspan="3">Eau Claire Formation</td><td>Proviso Member</td><td rowspan="2">Eau Claire</td><td rowspan="2">Shale and Carbonate</td></tr>
<tr><td>Lombard Member</td></tr>
<tr><td>Elmhurst Member</td><td rowspan="2">Mt. Simon</td><td rowspan="2">Sandstone</td></tr>
<tr><td colspan="2">Mt. Simon Formation</td></tr>
<tr><td>PRECAMBRIAN</td><td colspan="2">Lithostratigraphic units not detailed</td><td>Precambrian</td><td>Crystalline</td></tr>
</table>

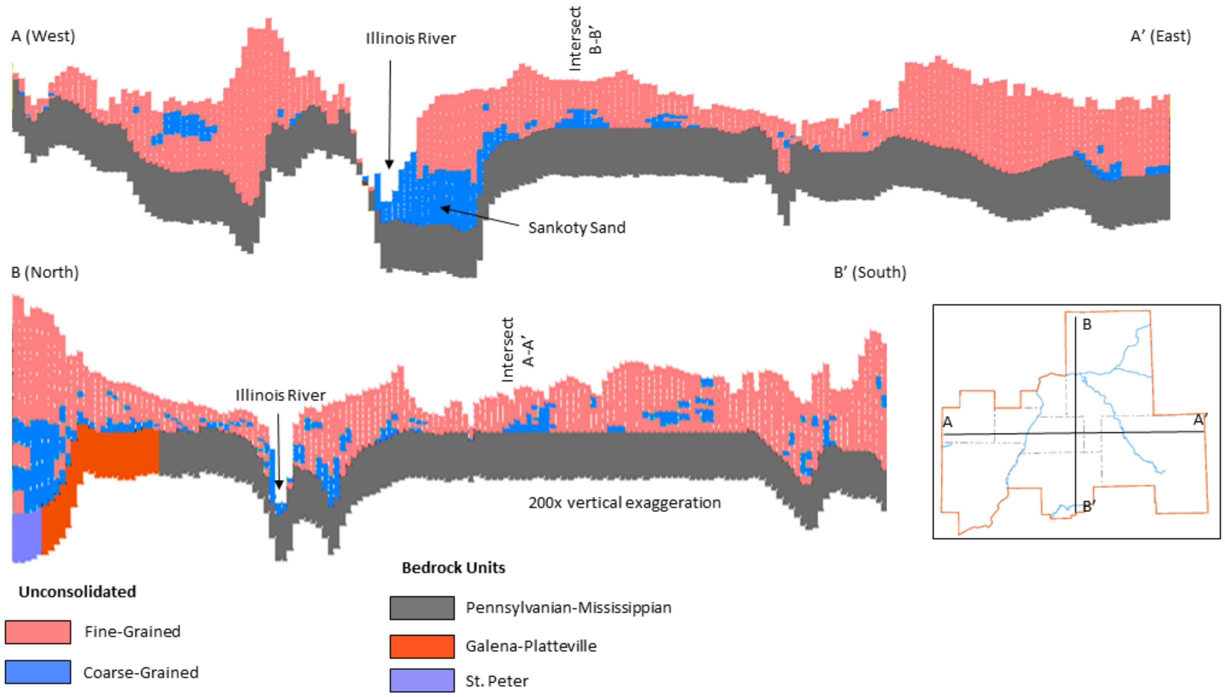


Figure 11: East-west (A–A') and north-south (B–B') cross-sections depicting the conceptualization of unconsolidated materials throughout the Middle Illinois WSPR used in the groundwater flow model. Inset map shows location of cross-sections in region.

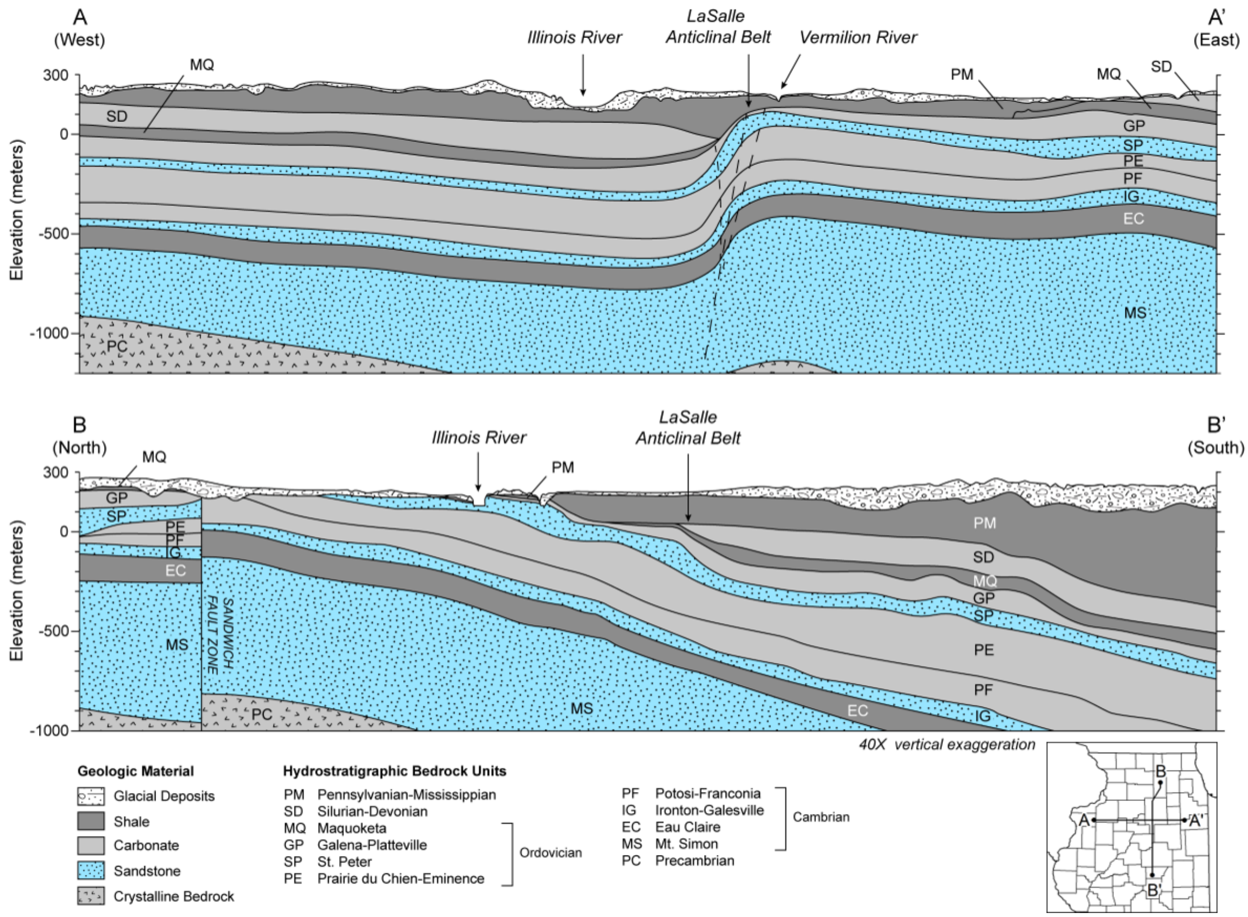


Figure 12. East- west (A) and north- south (B) geologic cross-sections showing the hydrostratigraphic units of the study area. Note the presence of the Illinois River, which is connected to the sandstone aquifers in LaSalle County. Also note the presence of the LaSalle Anticlinal Belt, which is likely faulted through most of the bedrock hydrostratigraphic units.

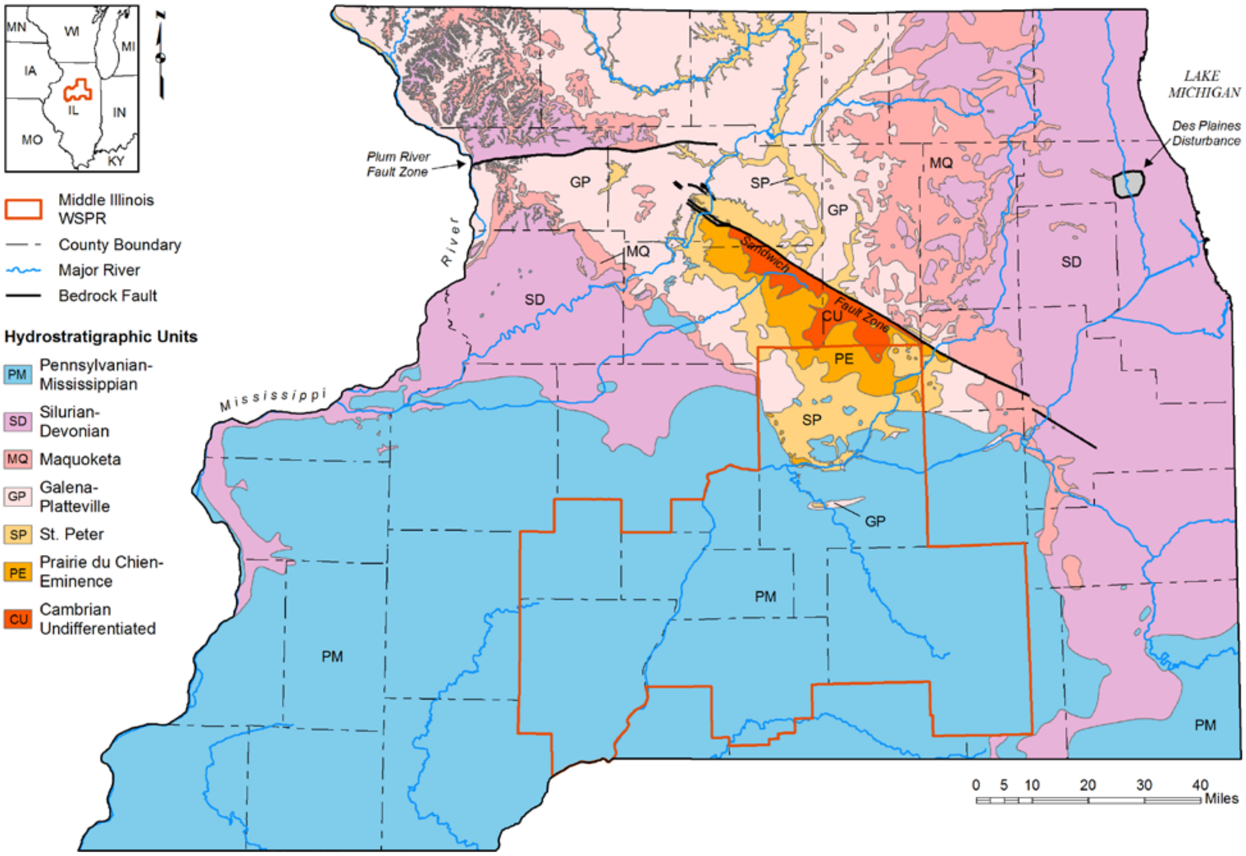


Figure 13. Hydrostratigraphic units present at the bedrock surface (Kolata et al., 2005, Mudrey et al., 1982). Note that all units below the Prairie du Chien-Eminence Unit are grouped into a Cambrian Undifferentiated category.

## 3.4 The Illinois Groundwater Flow Model

The primary tool utilized by the ISWS to understand the impacts of different water supply planning scenarios on groundwater availability is the Illinois Groundwater Flow Model (Abrams et al., In press). This model is developed using the finite-difference code MODFLOW (McDonald and Harbaugh, 1988). In the model, the aquifer system is divided into discrete blocks, each with its own set of hydrologic properties that control groundwater flow. Each hydrostratigraphic unit shown in Figure 12 is simulated as a layer in the model. Since many hydrostratigraphic units are not present throughout the entire model domain, we utilize the modern unstructured grid solver, which allows such layers to be removed from the solution (Panday et al., 2013). Features that can interact with groundwater (such as surface waters and wells) can also be simulated within each block. Model development is facilitated by using a number of tools, including the graphical user interface Groundwater Vistas 6 (Rumbaugh and Rumbaugh, 2010) and ESRI's ArcGIS 10.3 for spatial analyses and visualization (ESRI, 2015).

The Illinois Groundwater Flow Model extends over the northern half of Illinois, southern Wisconsin, and western Indiana. This large scale allows the simulation of far-reaching impacts of withdrawals from the sandstone aquifers. Because of the large regional domain, the model has a relatively crude grid spacing, 2,500 feet on a side. This is sufficient for regional assessments of both deep and shallow groundwater. However, to simulate local well-stream interactions, which are critical in areas such as Peoria and Ottawa, model refinement is required. The Illinois Groundwater Flow Model provides a means to develop such a refined model, particularly because the geologic data used in the Illinois Groundwater Flow Model is preserved in geodatabases on a 625 foot grid, with other data (such as stream networks) preserved at an even finer grid.

Models developed at the ISWS have a number of capabilities useful for water supply planning purposes in the Middle Illinois region:

1. By calibrating model results to observed data collected over the history of pumping in the region, the model can provide insight into groundwater flow patterns. Understanding a groundwater flow system is critical in evaluating future water supply plans.
2. The model is deterministic, meaning that groundwater withdrawals are inputs to the model. This allows us to simulate multiple future water supply scenarios to assess their impacts on the aquifers of a region. For example, in this report, we compare impacts of the three different demand scenarios out to the year 2060.
3. The model facilitates the investigation of groundwater-surface water interactions. Surface water can be both a sink and a source of groundwater; as a result, withdrawals in shallow aquifers often affect natural groundwater discharge to surface waters. This can be particularly detrimental to the ecology of small streams that rely on groundwater to maintain some level of flow during periods of minimal precipitation (Zorn et al., 2008).
4. Though not directly related to water supply planning, models allow for the simulation of aquifer contamination, including both localized point sources, such as landfills or industrial discharges, and sources that are more diffuse, such as chloride from road salt applications or nitrate from agricultural activity. Both the history of contamination and potential best-management practices to reduce contamination can be simulated.

## 3.5 Sand and Gravel Aquifers in the Middle Illinois WSPR

The thick sand and gravels along the Illinois River from Hennepin to Peoria are a productive aquifer in the Middle Illinois WSPR, as indicated by the transmissivity map of the unconsolidated materials in Figure 14. Transmissivity, which is the product of saturated thickness and hydraulic conductivity, is an indicator of how productive an aquifer can be. In other words, the more transmissive the unit, the less drawdown one would expect due to pumping. Figure 15 depicts withdrawal data for public supply, self-supplied commercial and industrial, and some irrigation wells in sand and gravel aquifers. These sand and gravels are often referred to as the Sankoty Aquifer and have been associated with relatively old glacial advances. Recent work, however, shows that much of the sand is actually younger than the Sankoty (McKay et al., 2010). This fact has significant implications for the hydrologic connection of the Illinois River to the sands in the region. In some areas, the Illinois River, as well as the younger sand adjacent to its modern valley, cuts into or below the older Sankoty sand (Figure 16). Where this happens, the Sankoty sand and gravels are either not hydrologically connected to the Illinois River or a considerable thickness is dry. This allows for the mining of dry sand very close to the Illinois River.

The sand and gravel aquifers in the Peoria area were studied by Marino and Schicht (1969) and Burch and Kelly (1993) to help assess the impacts of heavy pumpage on groundwater levels. Because the gradient of the Illinois River is so flat, groundwater flow generally follows a perpendicular flow path from the valley walls toward the river (Figure 17). However, local cones of depression have developed around the largest pumping centers in Peoria. In an effort to mitigate the drawdown and cool the river water, the ISWS constructed and monitored artificial groundwater recharge pits next to the river (Suter and Harmeson, 1960). Studies at Henry in Marshall County by Ray et al. (1998) also show groundwater flow being perpendicular to the river. In addition, these studies indicate that flooding along the river can also influence the groundwater flow system as well as groundwater quality.

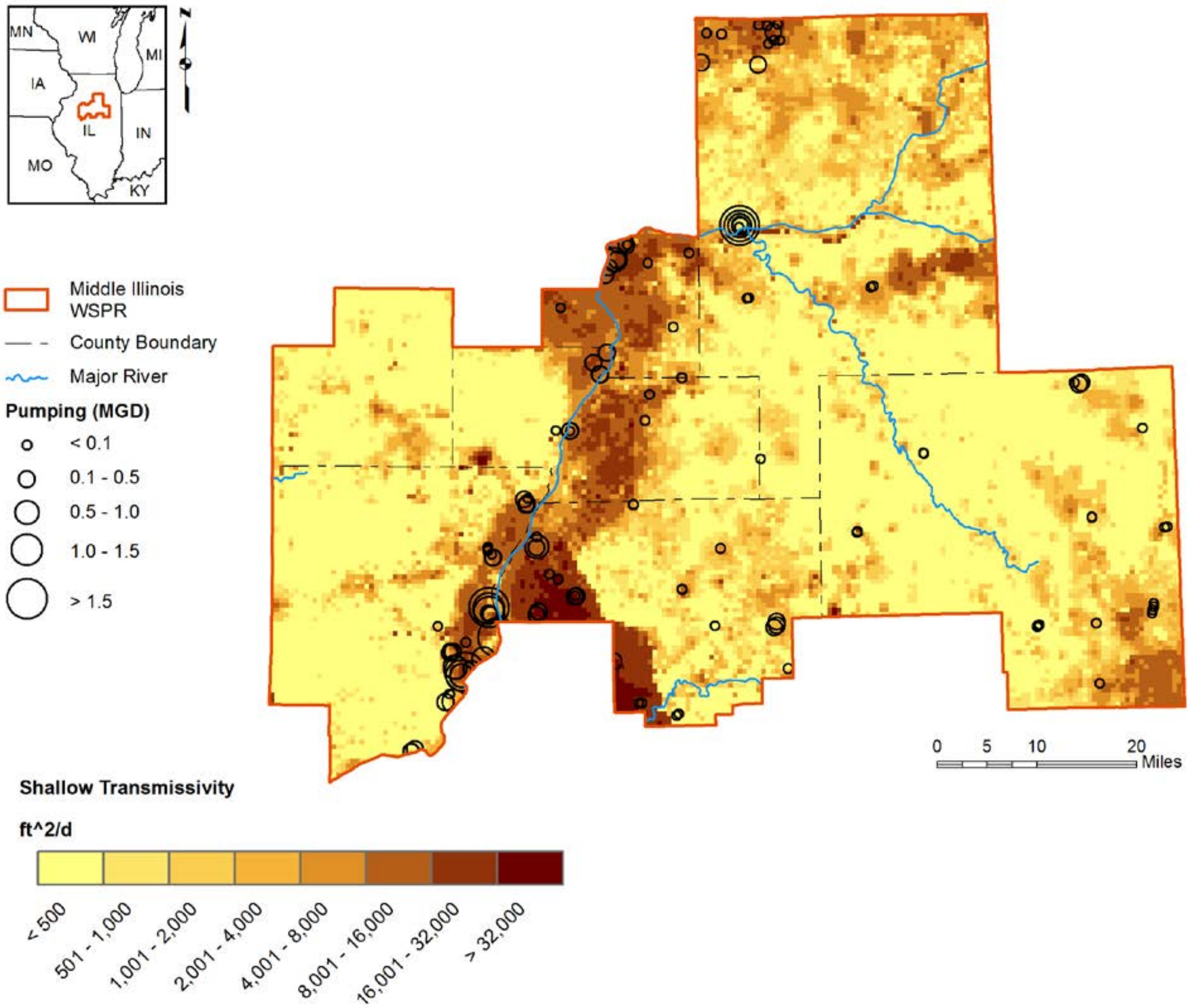


Figure 14. Shallow transmissivity in Middle Illinois (combined sand and gravel and weathered bedrock)

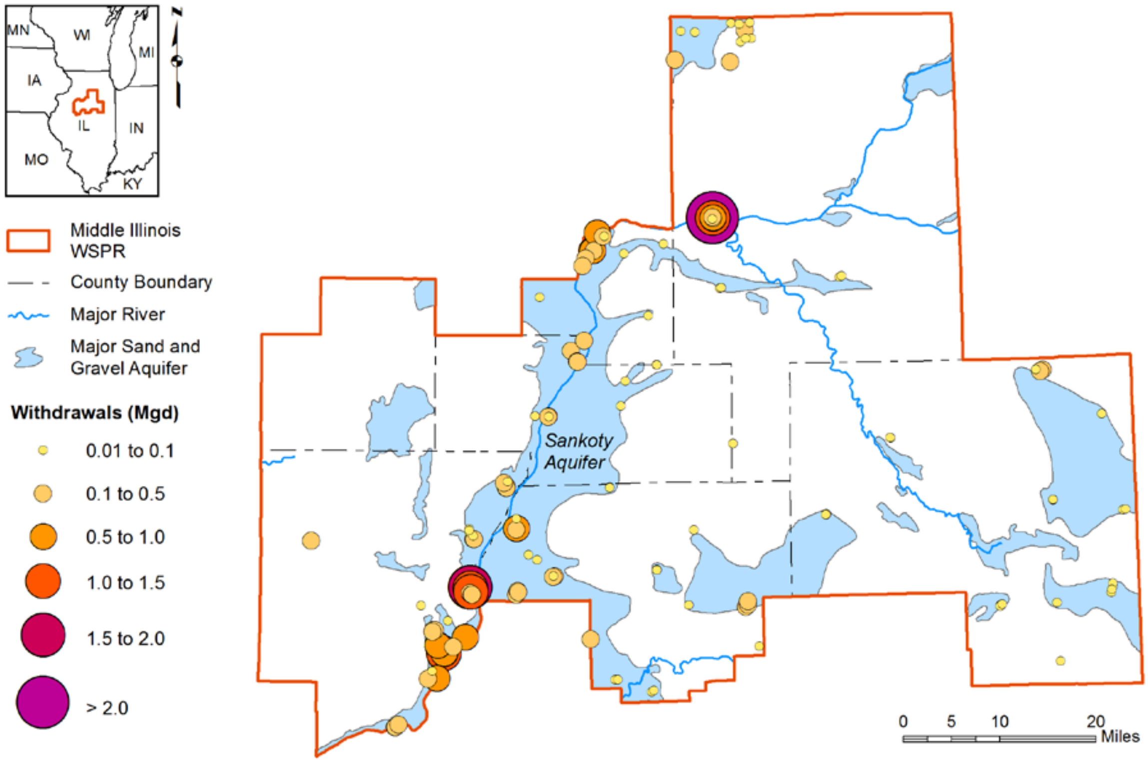


Figure 15. Withdrawals of water in Mgd from sand and gravel wells reporting to IWIP

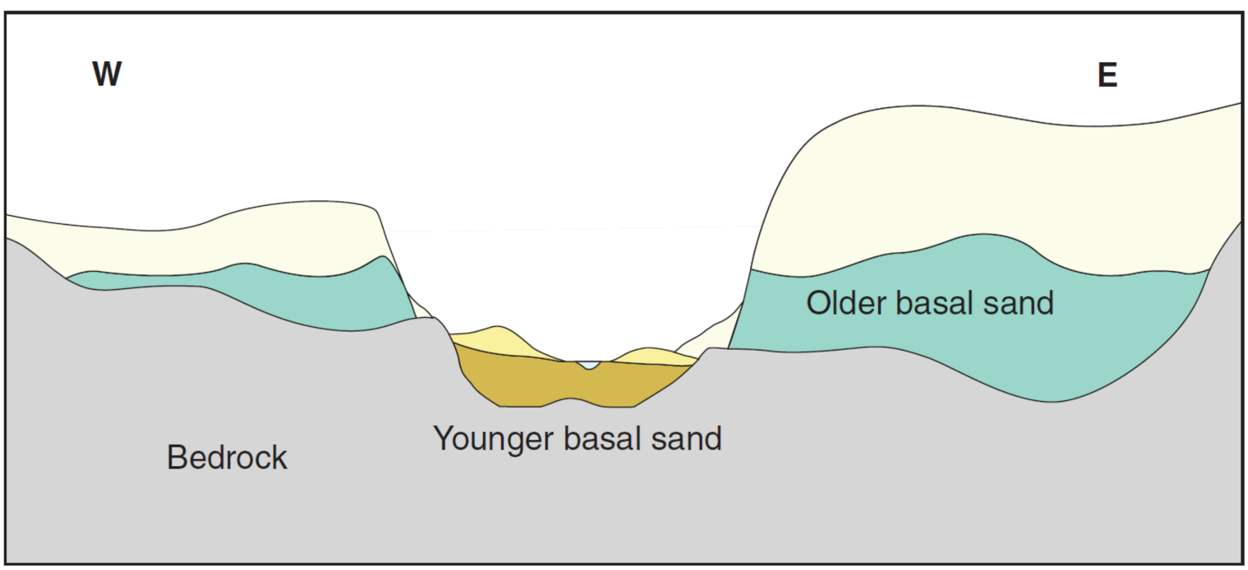


Figure 16. Incision of the Illinois River into the bedrock and beneath the older basal (Sankoty) sands. Image from Berg et al. (2012)

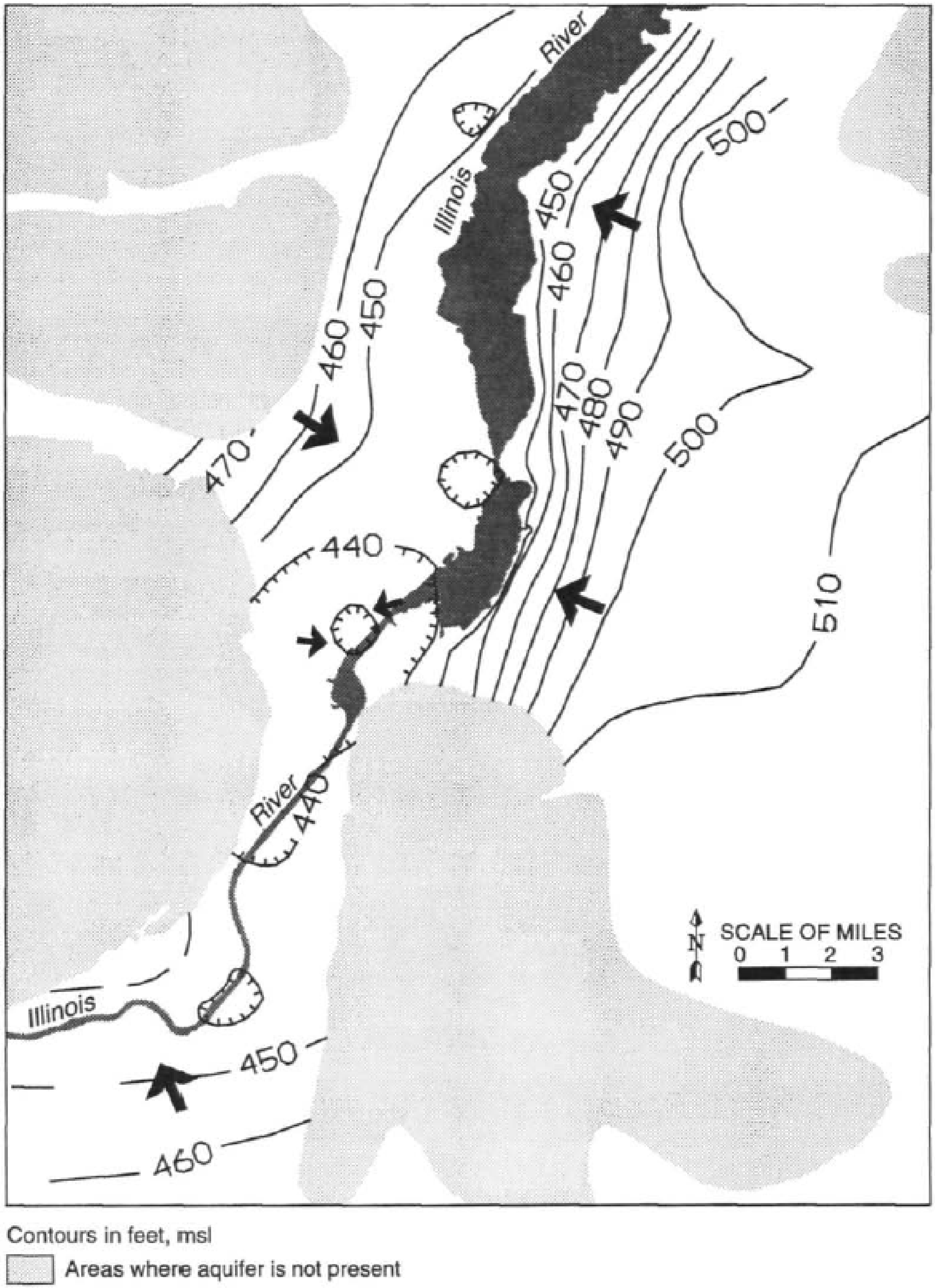


Figure 17. Potentiometric surface for 1990-1991 in the Peoria-Pekin basal sand and gravels. Image from Burch and Kelly (1993)

### *3.5.1 Model Simulations*

Most withdrawals from the sand and gravel aquifers in the Middle Illinois WSPR occur in the basal sand and gravels; that is, the sand and gravels directly overlying the bedrock. Layer 9 of the Illinois Groundwater Flow Model simulates these basal unconsolidated materials, which consist of sands and gravels (white areas in Figure 18) and fine-grained materials (hashed areas in Figure 18). In local areas, particularly along deeply incised rivers and streams, unconsolidated materials are limited or non-existent (gray areas in Figure 18). For example, the Illinois River deeply incises into the bedrock aquifers, leaving very limited unconsolidated materials throughout central LaSalle County. This forces most communities and industries in the area to use the sandstone aquifers.

The model is reasonably well calibrated to water levels from the basal unconsolidated materials, at least for a regional assessment. Lacking a synoptic measurement of well-water levels in the region, we utilized water level data extracted from the ISWS wells database, generally measured when a well was drilled. The spatial scatter in data is expected, since most wells are located at the center of a 10 acre plot rather than their actual location. Terrain differences in the region are extreme enough to induce scatter due to this error in location. Notably, the very lowest observed water levels, which occur at Peoria, generally are too high in the model simulation. This could be due to a number of factors, including improper locations of observed heads, too much recharge, too low a hydraulic conductivity, improper well-stream geometry from the gridded nature of the model, and transient effects not captured within the model’s annually averaged conditions.

The potentiometric surface, which is essentially a contour map of the water levels in an aquifer, is shown for the basal unconsolidated materials in Figure 19. As is typical with most groundwater systems, the lowest elevations occur along the rivers that are hydrologically connected to the unconsolidated materials. This is most evident along the Illinois River where groundwater elevations near the river approach the simulated river elevation of 440 feet above mean sea level (AMSL) in Peoria County. Even with this hydrologic connection, however, a localized cone of depression has formed near the Illinois River at Peoria. The cone simulated by the model is currently too deep, likely on account of the distorted well-stream geometry of the coarse model and the simulation of multiple wells in a single cell.

The impact of future scenarios varies depending upon location. In the CT scenario (Figure 20), water levels in LaSalle and Woodford Counties generally decline or stay relatively constant from 2016 to 2060. Much of the decline in LaSalle County appears to be related to underlying sandstone withdrawals rather than the unconsolidated aquifers. The declines in Woodford County (Figure 20) are related to withdrawals from lower transmissive units in the eastern part of the county or primarily municipal withdrawals from higher transmissive sand and gravels in Tazewell and McLean Counties to the south (Figure 14). Five public supplies experienced very localized drawdown that approached or exceeded 20 feet in the CT 2060 model simulations: Ransom, Rutland, Washburn, Lowpoint Water District, and Congerville. However, Ransom started purchasing water from Illinois American in 2016 with water originating from Streator; new model simulations at the ISWS will not include future pumping for Ransom.

In contrast to the declining water levels in LaSalle and Woodford Counties, water levels in Peoria and Dwight increase, reflecting the assigned local demands remaining relatively stable or decreasing from 2016 to 2060. Peoria, however, has some important industries that use groundwater; these industries were assumed to have constant withdrawals into the future.

Additional industrial demands could put stress on the local aquifers that were not simulated in the CT scenario.

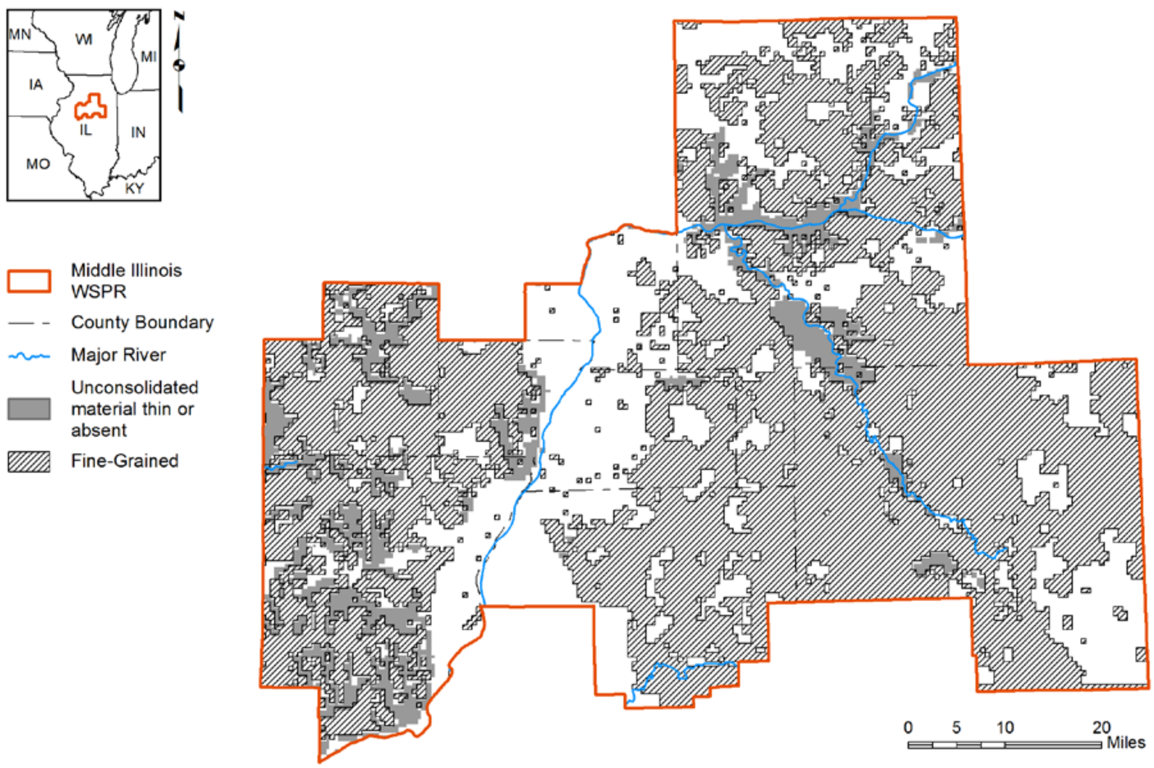


Figure 18. Location of fine-grained materials and areas of limited unconsolidated materials in the Middle Illinois WSPR above the bedrock surface. White areas indicate the presence of the sand and gravel aquifer

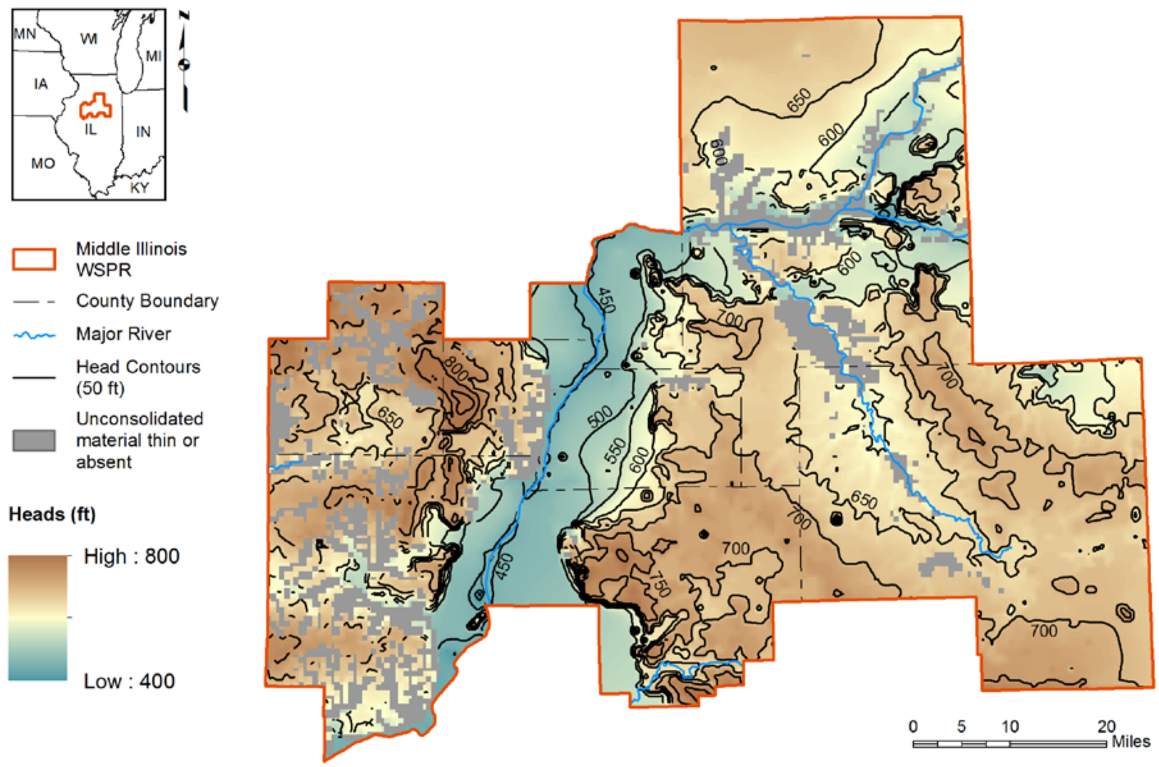


Figure 19. Simulated potentiometric surface of the basal unconsolidated materials for 2016. Purple zones represent areas where unconsolidated materials have limited thickness and are not simulated

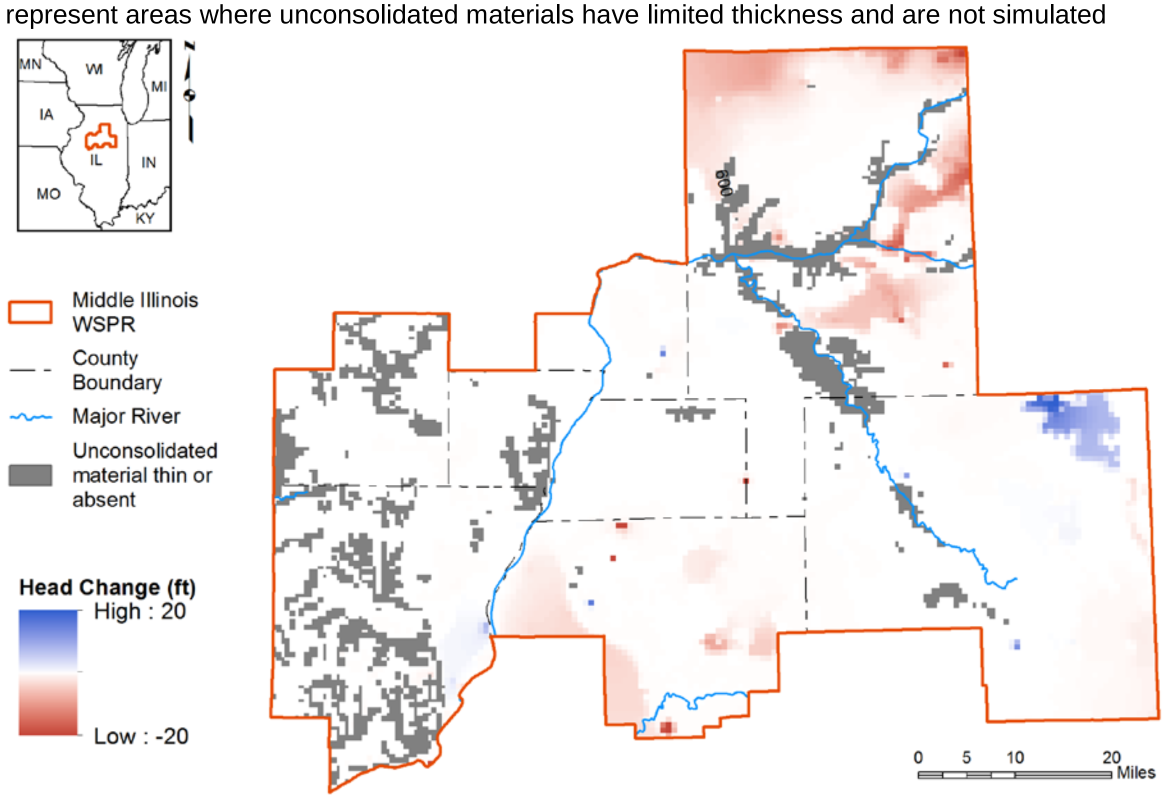


Figure 20. Simulated head change of the basal unconsolidated materials from 2016 to 2060 using the Current Trends (CT) Scenario

### 3.5.2 Water Quality

Groundwater quality data for the sand and gravel aquifers discussed in this report come from the ISWS Groundwater Quality Database. This statewide database contains data for more than 60,000 samples collected from wells in Illinois dating back to the 1890s. Data sources include public water supply well data (collected by IEPA since the 1970s and from other sources before then), ISWS Public Service Laboratory (PSL) data, primarily from domestic wells, ISWS research project data, and several other sources. Note that the domestic well samples may be biased towards poorer water quality, in that domestic well owners are more likely to contact PSL for a sample analysis if they suspect something is wrong with their well water quality.

The two most important contaminants in shallow sand and gravel aquifers in the Middle Illinois WSPR are arsenic and nitrate. Arsenic concentrations greater than the drinking water standard (10 micrograms per liter [µg/L]) are common in the region, especially in Woodford County (Figure 21). Arsenic is a naturally occurring contaminant that is present in the sediments that make up the aquifer; it dissolves into the groundwater when geochemical conditions are suitable. Widespread geographic variability exists in arsenic concentrations, which has also been observed in other parts of the state (Kelly and Holm, 2011, Kelly et al., 2005).

Nitrate-nitrogen ($NO_3$-N), on the other hand, is an anthropogenic contaminant, with various sources, including agricultural activities (synthetic fertilizer, livestock manure, soil disruption) and human waste (sewage and septic systems). The drinking water standard for $NO_3$-N is 10 milligrams per liter (mg/L), and concentrations greater than 2 to 3 mg/L generally indicate contamination from human sources. Elevated concentrations of $NO_3$-N were found in a number of wells located along the Illinois River, while concentrations were much lower in wells away from the river (Figure 22). Elevated $NO_3$-N is indicative of the shallow, unconfined alluvial aquifer in the Illinois River Valley. Aquifers like these are vulnerable to surface activities, including runoff from cropped fields and septic discharge.

Chloride ($Cl^-$) is a common contaminant that generally indicates human activities, although natural sources exist as well. Where there are no significant natural sources, concentrations greater than 10 to 15 mg/L generally indicate human contamination. In the Middle Illinois Region, $Cl^-$ concentrations were elevated in certain areas (Figure 23). In the area near Starved Rock, increases were likely due to an upwelling of brines from deeper bedrock formations. For example, an old Salt Well on the Starved Rock property, which was used for making salt by the early settlers, has very high $Cl^-$ concentrations. Elevated levels in other parts of the region are probably the result of agricultural runoff, septic/sewage, and/or road salt runoff. Road salt runoff may be the reason for the relatively elevated levels in the Peoria area.

Well depth is an important variable for $NO_3$-N and $Cl^-$, but not for arsenic (Figure 24). The sources for both $NO_3$-N and $Cl^-$ contamination are found at or near the land surface, so it is not surprising that shallower wells tend to have higher concentrations of these parameters. Nitrate-N and $Cl^-$ concentrations were not correlated, indicating that the major sources for these two contaminants are different (Figure 24).

In summary, there are water quality issues related to the sand and gravel aquifers in the region. Those using these aquifers will most likely need to deal with high nitrate and/or arsenic concentrations.

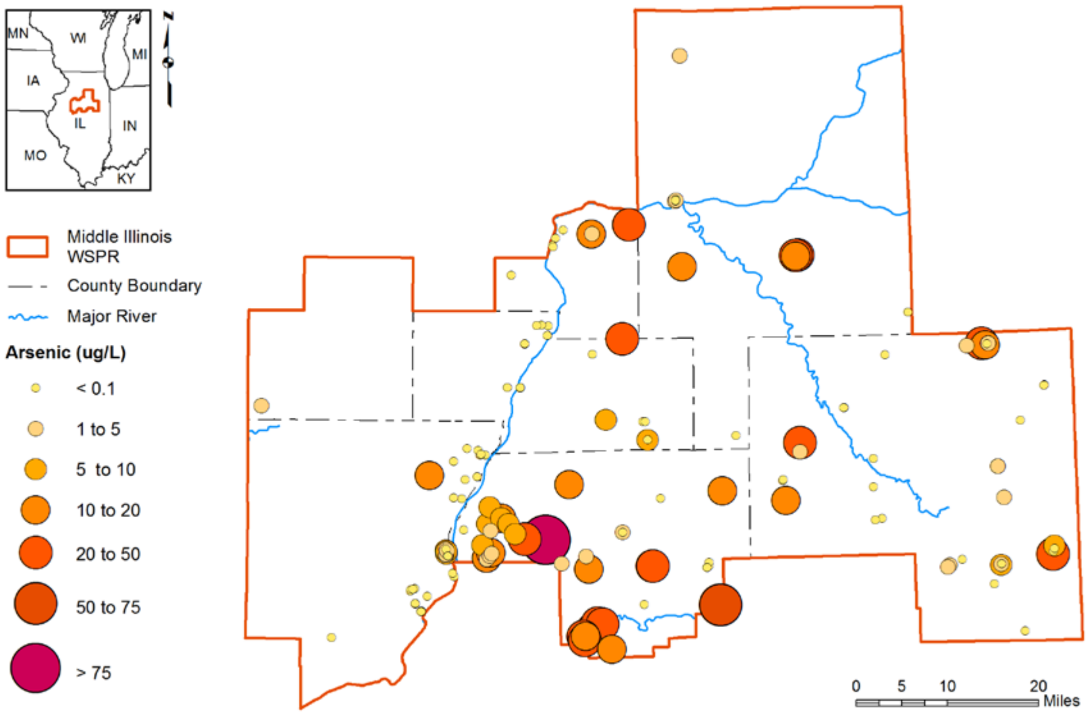


Figure 21. Arsenic concentrations in sand and gravel aquifers in the Middle Illinois Region. The drinking water standard is 10 µg/L

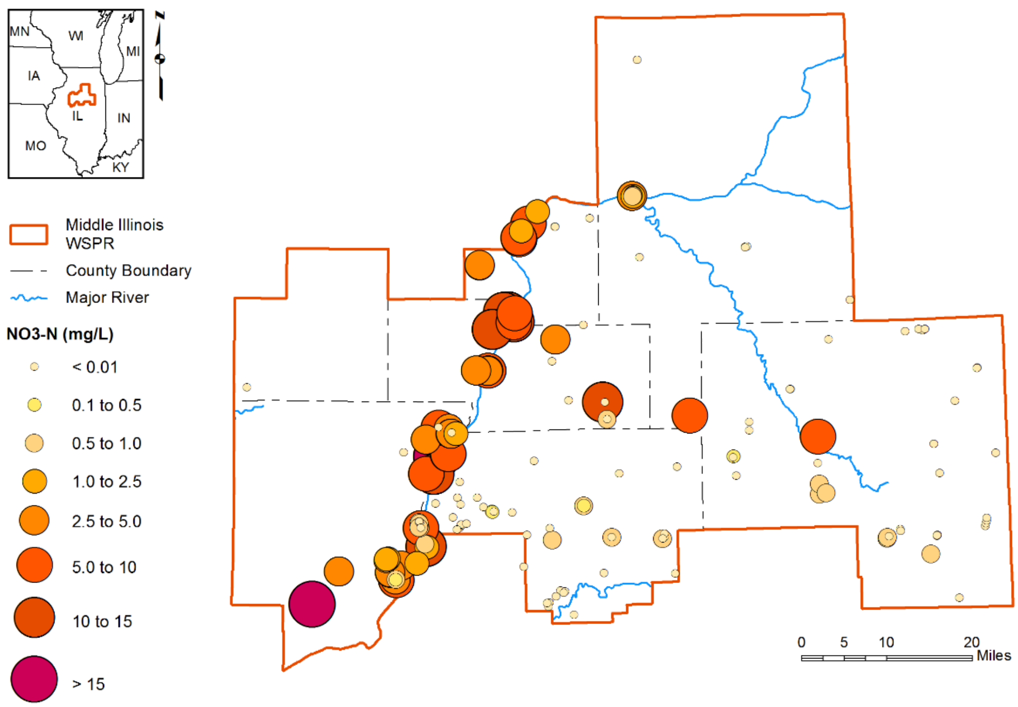


Figure 22. Nitrate-N concentrations in sand and gravel aquifers in the Middle Illinois Region. The drinking water standard is 10 mg/L

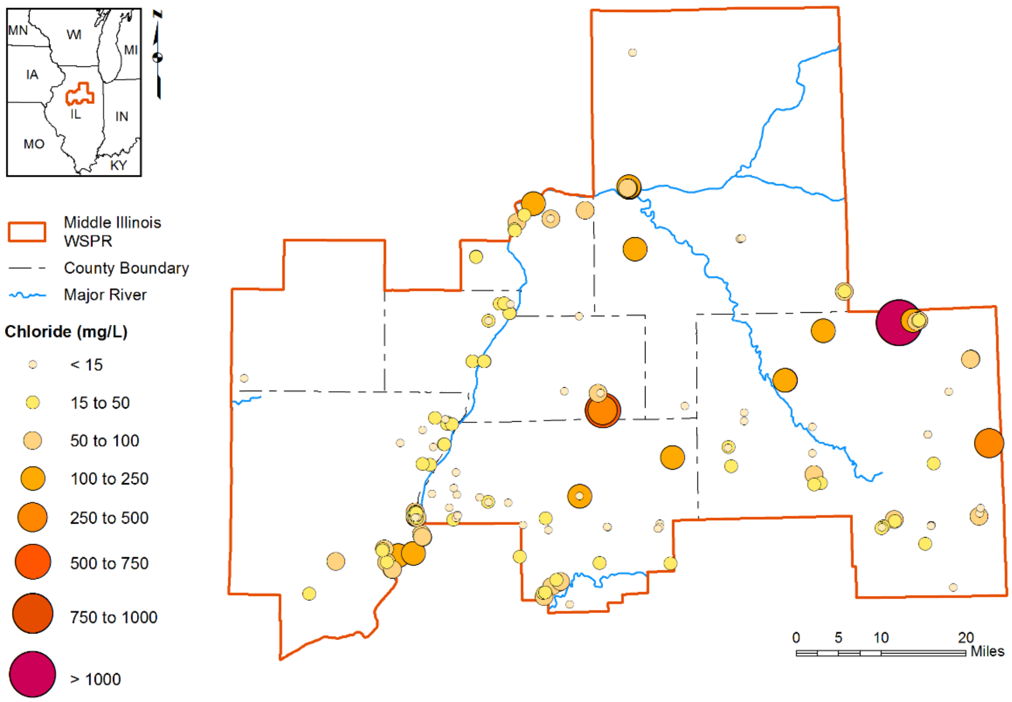


Figure 23. Chloride concentrations in sand and gravel aquifers in the Middle Illinois Region. The secondary drinking water standard is 250 mg/L

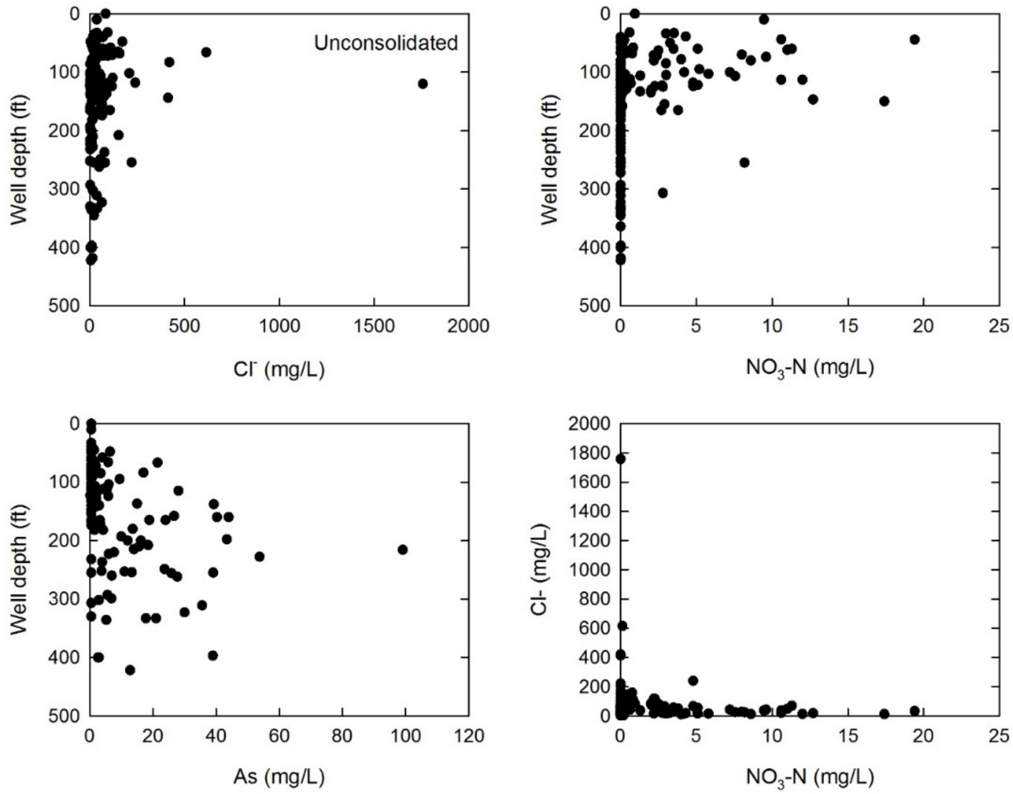

Figure 24. Chloride, nitrate-N, and arsenic concentrations as a function of depth (feet) in sand and gravel aquifers in the Middle Illinois Region. Nitrate-N vs. chloride concentrations (lower right).

## 3.6 Shallow Bedrock Aquifers in the Middle Illinois WSPR

Weathered bedrock aquifers are not heavily used in the Middle Illinois WSPR, primarily because of the lack of carbonate units at the bedrock surface within the region (Figure 13) and poor water quality. As a result, we did not model flow in these aquifers.

Most of the wells open to these aquifers are in the western part of the region. Thin lenses or layers of sandstones and carbonates in the Pennsylvanian-Mississippian Unit support small withdrawals in local areas, particularly in Stark County.

Water quality in these aquifers is generally poor, typically worse than in the region's deep sandstone aquifers. A search of the ISWS Groundwater Quality Database found approximately 40 wells open to the shallow bedrock aquifers that were sampled between the 1960s and 2008. The median total dissolved solids (TDS) value for these samples was 1439 mg/L, almost three times the secondary drinking water standard of 500 mg/L, with a maximum of 3452 mg/L (secondary standards are not enforced but are for aesthetic purposes; water with TDS > 500 mg/L begins to taste salty).

## 3.7 Sandstone Aquifers in the Middle Illinois WSPR

Three sandstone aquifers are used in the Middle Illinois region. From the shallowest to the deepest, these are the St. Peter, New Richmond, and Ironton-Galesville Sandstones (Willman et al., 1975). In the Middle Illinois WSPR, the St. Peter Sandstone comprises almost all of the St. Peter Hydrostratigraphic Unit (Figure 12). The St. Peter Sandstone is at the bedrock surface in most of the northern half of LaSalle County, although it is eroded away at the northern border of the county (Figure 13). The St. Peter Sandstone is hydrologically connected to the Illinois River in portions of LaSalle County.

The New Richmond Sandstone, which is contained within the Prairie du Chien-Eminence Unit (Figure 12), is also near the bedrock surface in LaSalle County. Here, it often serves as an aquifer, although wells open to the New Richmond are also commonly open to the overlying St. Peter or underlying Ironton-Galesville Sandstones. For these reasons, we do not explicitly simulate the New Richmond Sandstone in the groundwater flow model nor include it as its own hydrostratigraphic unit. The New Richmond Sandstone is not commonly used in the rest of Illinois.

The Ironton-Galesville Sandstone comprises the entire Ironton-Galesville Unit (Figure 12) and consists of well-rounded quartz sand grains similar to the St. Peter Sandstone. In the Middle Illinois WSPR, the Ironton-Galesville Sandstone is overlain and separated from the St. Peter Sandstone by two predominantly unweathered carbonate hydrostratigraphic units, the Prairie du Chien-Eminence and the Potosi-Franconia, which together function as an aquitard.

Many high-capacity or industrial wells in the Middle Illinois WSPR penetrate to one or more sandstone aquifers. These sandstone wells are generally drilled where shallower sand and gravel aquifers are absent or cannot provide the necessary volumes of water. The exception to this is in LaSalle County, especially north of the Illinois River, where there are many sandstone wells on account of the geologic structures that have brought the St. Peter and New Richmond Sandstones up to much shallower depths (Figure 12; Figure 13).

In 2014, the ISWS conducted its largest study of Cambrian-Ordovician sandstone aquifer heads in Illinois since 1980. This study included the entire Middle Illinois WSPR. The 2014 potentiometric surface of the Cambrian-Ordovician sandstone aquifers is shown in Figure 26. The highest heads were located in north-central Illinois. Heads that exceeded 600 feet above mean sea level (AMSL) in Illinois are generally located in the area where leakage to sandstone is relatively high because of the absence of shale. The exception to this is in LaSalle County, where even though shale is absent, heads fell below 600 feet. The sandstone in LaSalle County is close to the surface, so heads are controlled by elevations in the Illinois River, which range from 450 to 540 feet AMSL.

The majority of the sandstone in the Middle Illinois WSPR is covered by shale that limits the ability of water to flow vertically into the sandstone aquifers (Figure 13). As a result, withdrawals from these confined aquifers are not readily replenished by precipitation. Consequently, 25 to 50 feet of head decline has been observed since 1980 for most of the region (Figure 27). The largest head change in the Middle Illinois WSPR between 1980 and 2014 occurred in Marshall County. This finding is based on observations from wells in Toluca, Wenona, and Hopewell, although pumping from these facilities is not adequate to explain this change. Although it is possible that the measurements were wrong, this decline may also be attributable to withdrawals that were not reported to IWIP or a hydrogeologic complexity, such as a fault zone, that is not currently considered.

The highest demands from the sandstone aquifers occur in the northern half of LaSalle County (Figure 25). However, sandstone aquifers used in this area (St. Peter and New Richmond) are near the bedrock surface and receive relatively high rates of leakage to replenish any water withdrawn. Therefore, regional heads changed very little in LaSalle County from 1980 to 2014 (Figure 27). Relatively stable heads are also observed for two Ottawa wells (Figure 28). It appears that the large sand mining operations in the Ottawa area are not having a regional impact on heads in the Cambrian-Ordovician sandstone aquifers, although local and seasonal impacts were not assessed during this study. In contrast, heads at a nearby industrial facility well where shale overlies the sandstone have decreased by nearly 100 feet since data records began in the mid-1960s (Figure 28). This industrial facility does not fit the regional trend for the county, but it may provide evidence of a local complication, as will be discussed in the modeling section.

The 2014 potentiometric surface shown in Figure 26 is based on water levels obtained from production wells; as such, the surface represents the head of the most stressed sandstone aquifer in the region. However, the open intervals of wells vary throughout the state, with wells open to some combination of the St. Peter and Ironton-Galesville Sandstones dominating in northern LaSalle County; St. Peter-only wells dominate in the southern portion of the Middle Illinois WSPR. We have also developed potentiometric surfaces individually for the St. Peter and Ironton-Galesville Sandstones, where some head separation exists between sandstone units. A few trends are noted:

1. The St. Peter/New Richmond heads tend to be higher than the Ironton-Galesville heads in northern LaSalle County. Both aquifers are influenced by a regional head decline in the sandstone, attributable to statewide withdrawals that are focused in northeastern Illinois, where the center of the state's largest cone of depression is located (Figure 26). However, the St. Peter and New Richmond are near the surface and are hydrologically connected to surface waters, but the Ironton-Galesville is not. Consequently, the uppermost sandstones have considerably higher heads than the Ironton-Galesville. This is corroborated by numerous well records and an observation well in southwestern Kendall County, located at Newark, that shows 70 feet of head separation between the St. Peter and Ironton-Galesville. Furthermore, this monitoring well indicates water mounding in the St. Peter Sandstone, which has a head higher than the nearby Fox River, indicating significant recharge to this uppermost sandstone.
2. Along the Illinois River, heads converge between the St. Peter and Ironton-Galesville sandstones. This is likely due to the large number of public supply and industrial wells in this region that provide a hydrologic connection between the St. Peter/New Richmond and Ironton-Galesville Sandstones, removing the natural impedance to flow that the geology otherwise prevents. Both the St. Peter and New Richmond are either thin or not present along the Illinois River, forcing the drilling of deeper wells to the Ironton-Galesville.
3. The St. Peter heads tend to be lower than the Ironton-Galesville heads in the western and southern portions of the Middle Illinois WSPR. The preponderance of sandstone wells in this region are open only to the St. Peter, so the deeper Ironton-Galesville has not been used as a water source, with a few exceptions. In addition to the cost of drilling to the Ironton-Galesville in this region, which is very deep, the water quality is expected to be much worse than in the St. Peter. Continued demands for the foreseeable future will likely continue to use the St. Peter Sandstone in this region; two new wells in Bloomington, IL were recently drilled (just to the east of Woodford County). These are two of the most southerly deep sandstone wells currently active in the state.

Notably, the preceding analysis had limited observations from the Ironton-Galesville Sandstone, particularly in southern and western areas of the Middle Illinois WSPR. Without actual observations, Ironton-Galesville heads and head separation between sandstones are highly speculative in this region.

The analyses of observed water levels in the sandstone aquifers in Illinois have helped to guide our understanding of the impacts of deep withdrawals, as well as to foster questions regarding the regional impact of pumping. Understanding how the Middle Illinois WSPR is influenced by regional declines throughout the state will be paramount to understanding the long-term viability of the sandstone in the region. Two things are clear: 1) outside of LaSalle County, reported withdrawals are relatively small (Figure 25); and 2) outside of LaSalle County, a continued downward trend in water levels has persisted (Figure 27). This decline is slow, and there appears to be no immediate threat to the sandstone supplies in the Middle Illinois region. However, it is critical to understand why these declines are present because the reported withdrawals within the region do not appear to provide a satisfactory explanation. Furthermore, withdrawals from outside of the region could further exacerbate these declines.

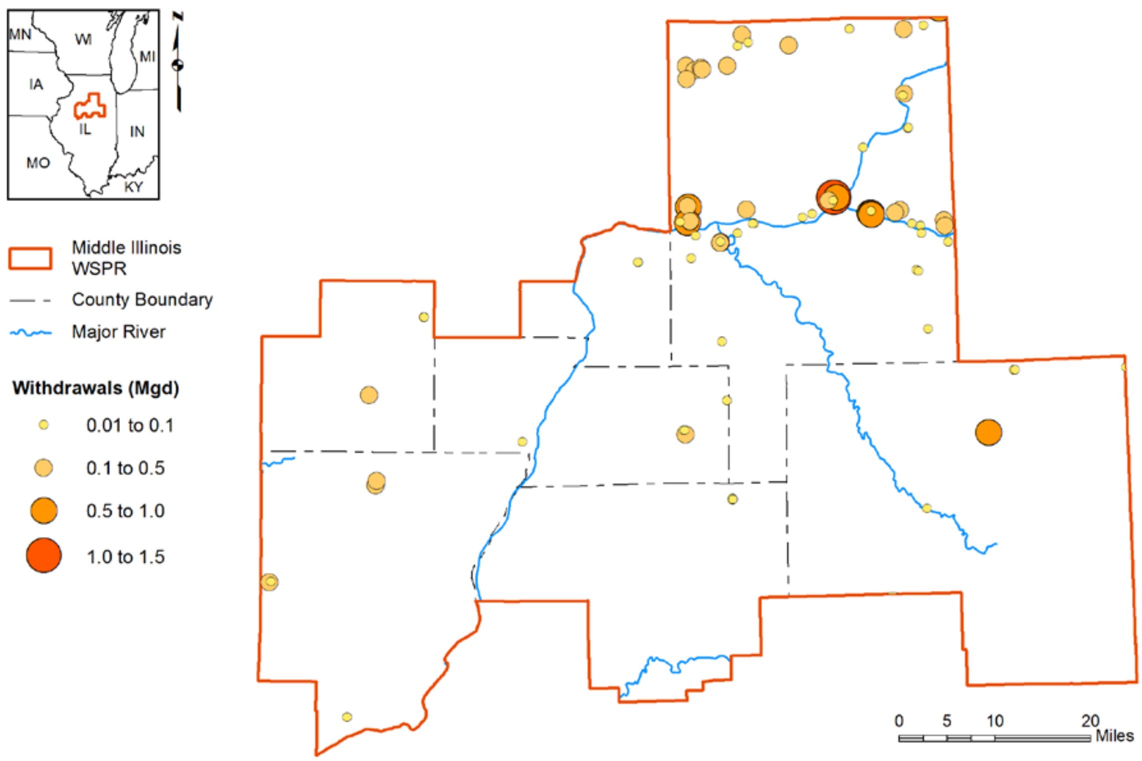


Figure 25. Withdrawals of water in millions of gallons per day (Mgd) from wells with a primary source of water from sandstone

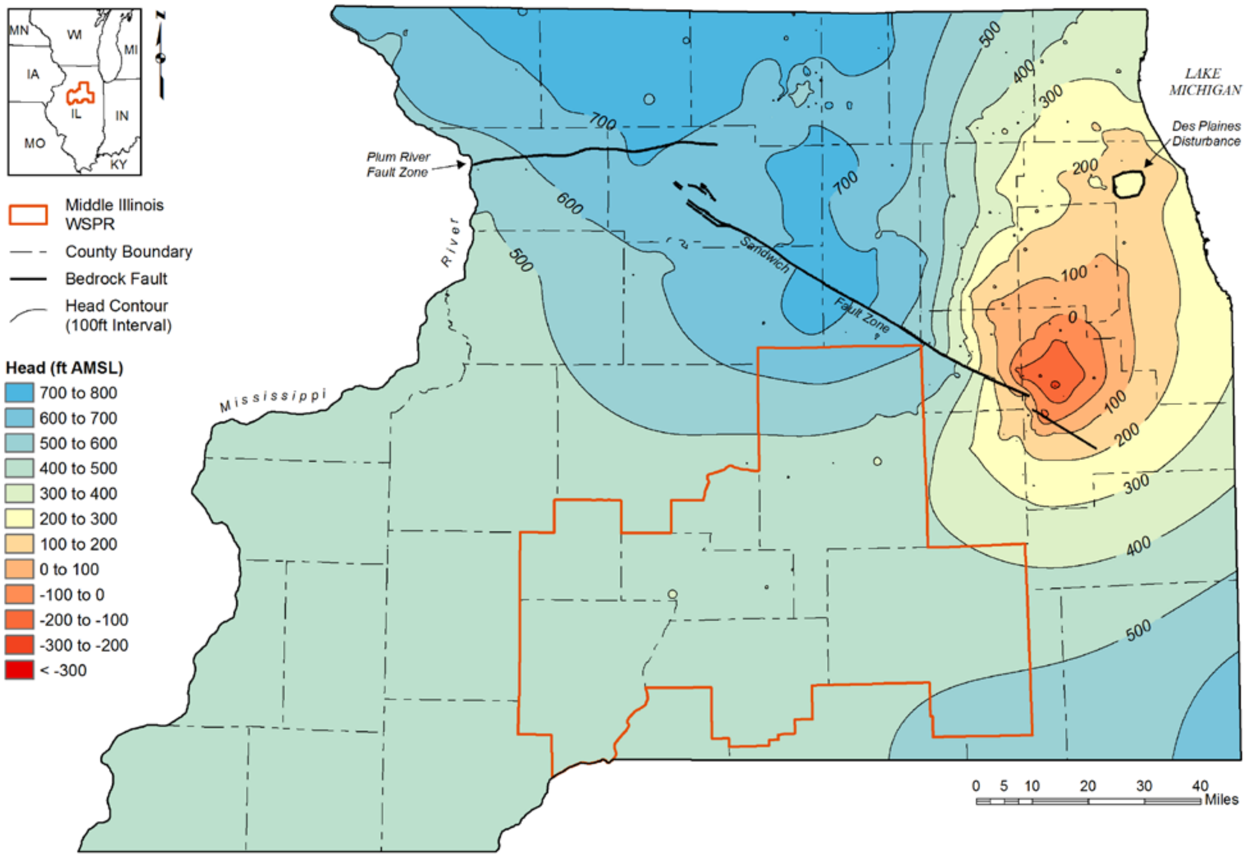


Figure 26. Potentiometric surface of the Cambrian-Ordovician sandstone aquifers in 2014 (modified from Abrams et al. (2015))

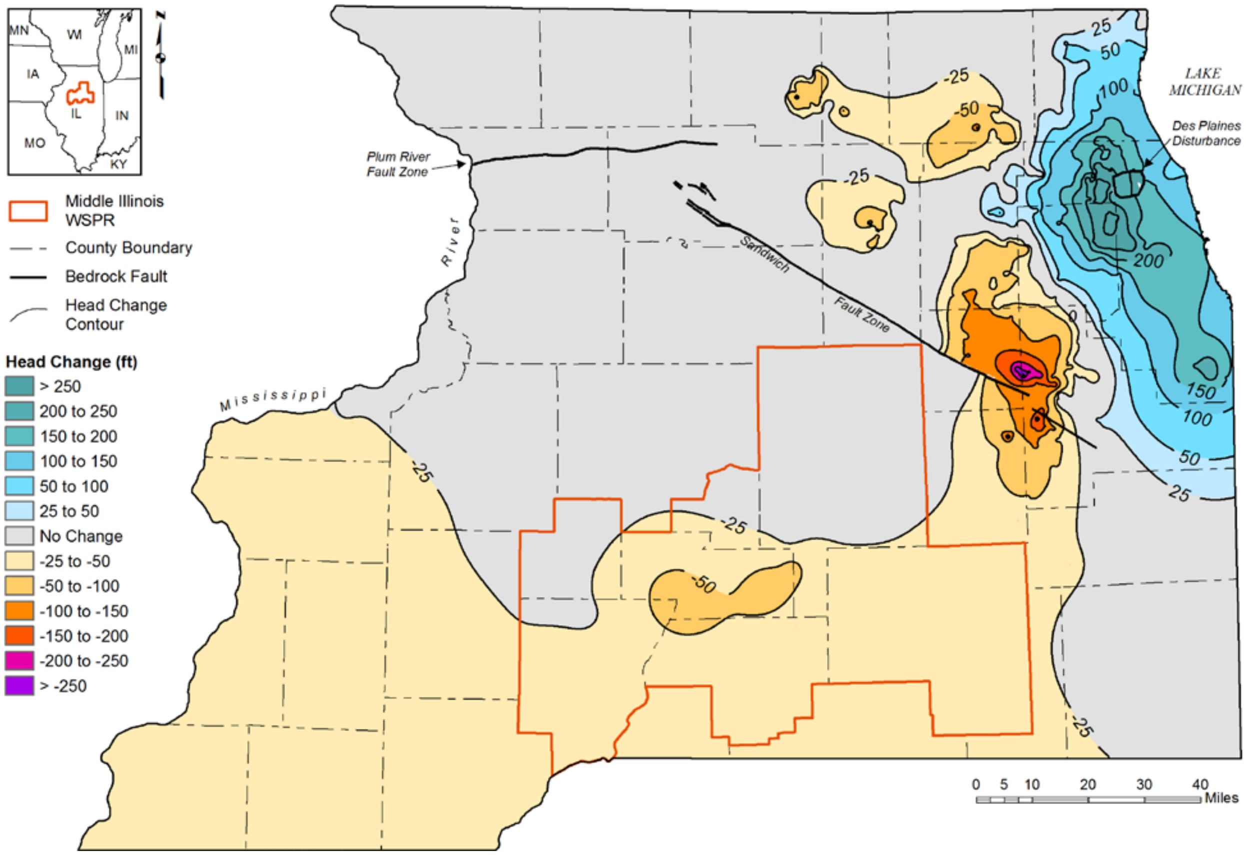


Figure 27. Change in heads from the Cambrian-Ordovician sandstone aquifers between 1980 and 2014

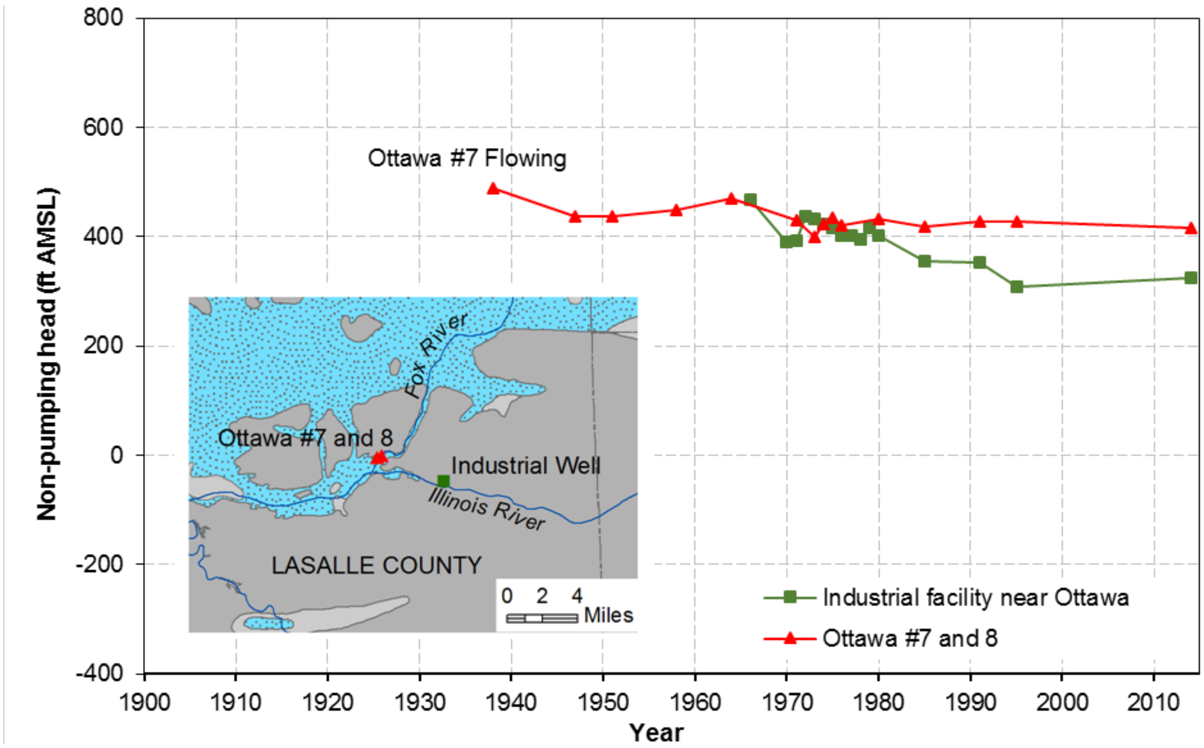


Figure 28. Observed heads at Ottawa public supply wells #7 (1938-1951) and #8 (1958-2014) and an industrial facility near Ottawa, IL. The blue area in the inset image depicts the location of the St. Peter Sandstone at the bedrock surface, and the dark gray area depicts where the sandstone is overlain by shale

To help explain the reason for water level declines in Illinois and to understand if any or all of the sandstone aquifers may become at risk in the future, we ran multiple simulations with the groundwater flow model. The model was calibrated to a long history of data, starting with predevelopment (1863) conditions. The simulated predevelopment contours (Figure 29) agree reasonably well with those developed in previous ISWS and USGS reports (Abrams et al., 2015; Anderson, 1919; Burch, 2002; Weidman and Schultz, 1915; Young and Siegel, 1992). Note the detailed contours in LaSalle County where the St. Peter has a strong hydrologic connection with the Illinois River. The model was also calibrated reasonably well to static head observations from 1980 and 2014 synoptic measurements. Because of the head differences within the sandstone aquifer system, we present results for both the St. Peter and Ironton-Galesville sandstones. Figure 30 depicts the simulated 2016 potentiometric surface of the St. Peter, which is absent in the northeastern corner of LaSalle County and in portions along the Illinois River near the city of LaSalle. The lowest simulated groundwater heads occur in east-central LaSalle County along the Illinois River and in northeastern Livingston County, which is consistent with the synoptic measurement (Figure 26). The highest heads occur in northwestern LaSalle County, also consistent with the observations. Some low points in Stark, Putnam, and Marshall Counties indicate drawdown from localized St. Peter withdrawals.

The potentiometric surface for the Ironton-Galesville in 2016 (Figure 31) has some distinct differences when compared with the St. Peter surface (Figure 30). In LaSalle County in particular, where Ironton-Galesville demands are greatest and the sandstone is not near the land surface (hence, it has minimal vertical infiltration), the heads are lower. A 400 foot contour is present in east-central LaSalle County, centered on an industrial facility using the Ironton-

Galesville. This low water level is also consistent with the hydrograph at this industrial facility where water levels are currently at approximately 350 feet (Figure 28). In contrast, water levels in the Ironton-Galesville are generally higher in the southern portion of the Middle Illinois WSPR when compared with levels in the St. Peter. This is largely due to the fact that only the St. Peter Sandstone is readily used in this area, and neither the St. Peter nor Ironton-Galesville receive much vertical infiltration on account of the thick, low permeable material overlying the units.

We simulated three future scenarios from 2016 to 2060, LRI, CT, and MRI. The distinctions between the results do not change the overall conclusions regarding water supply, so we show only the CT results. St. Peter heads changed by 10 to 30 feet in most of LaSalle, Stark, Marshall, and Putnam Counties (Figure 32), reflective of the projected slight decrease in groundwater demands over most of this region. Head declines of over 60 feet in northeastern Livingston County and 40 feet in eastern LaSalle County (Figure 32) cannot be attributed to the small withdrawals in these areas (Figure 25). Rather, withdrawals from northeastern Illinois, particularly Grundy and Will Counties, are the primary reason for this decline, as all future scenarios simulate an increase in the cone of depression centered on northeastern Illinois shown in Figure 26. Similarly, a 50 foot head decline in southern Woodford and Livingston Counties is due to new sandstone withdrawals at Bloomington that will commence in 2020.

The simulated Ironton-Galesville head change from 2016 to 2060 mimics the head change in the St. Peter Sandstone, with an additional decrease of 10 feet in most of the region (Figure 33). This slightly larger decrease is most likely because of the lack of vertical infiltration to this deepest sandstone and is likely a result of increasing Ironton-Galesville demands in northeastern Illinois more than it is a result of demands in the Middle Illinois WSPR. In most cases, the Ironton-Galesville is not used as a water supply in this region.

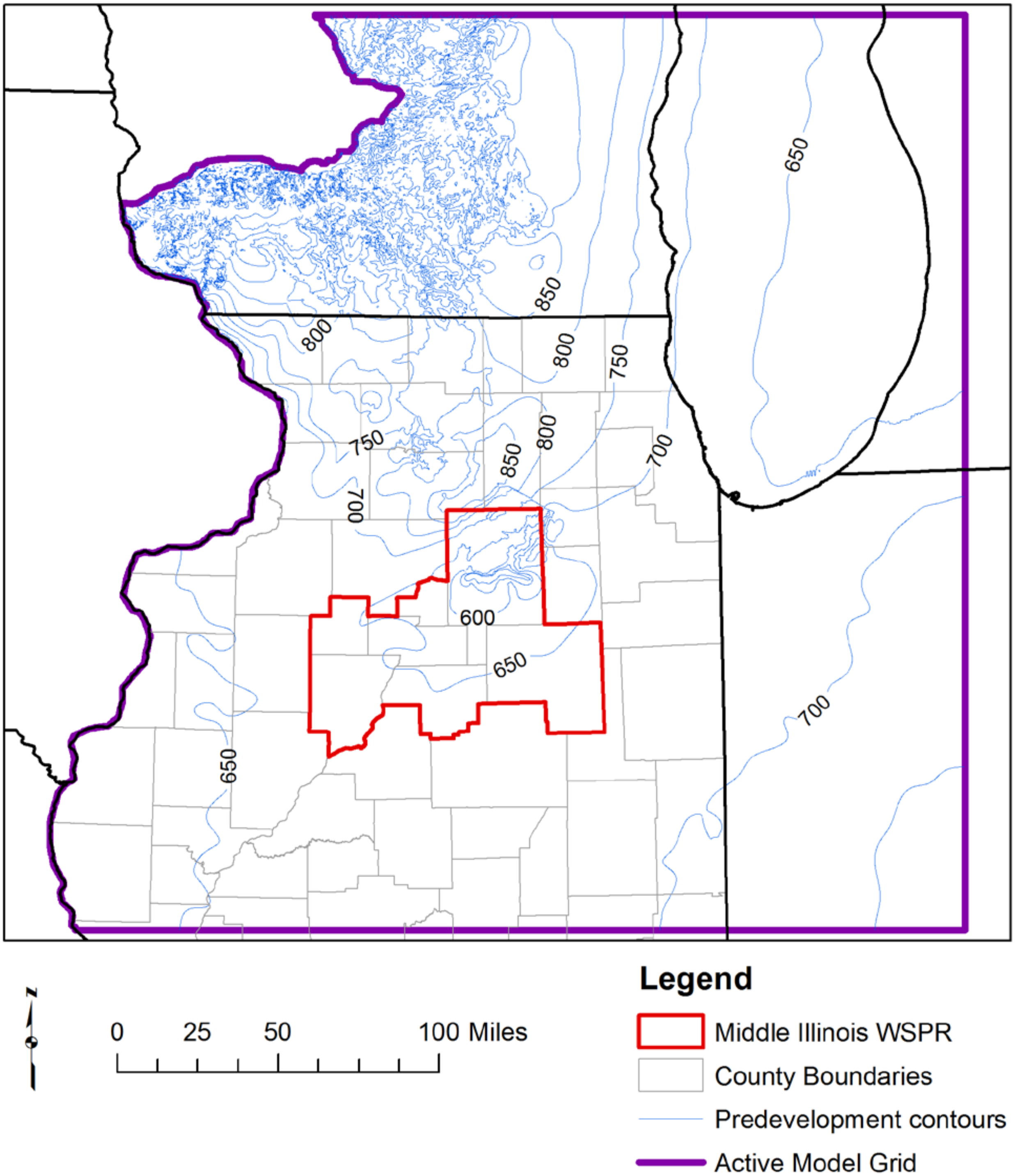


Figure 29. Predevelopment contours for the Cambrian-Ordovician sandstone aquifer system from the groundwater flow model

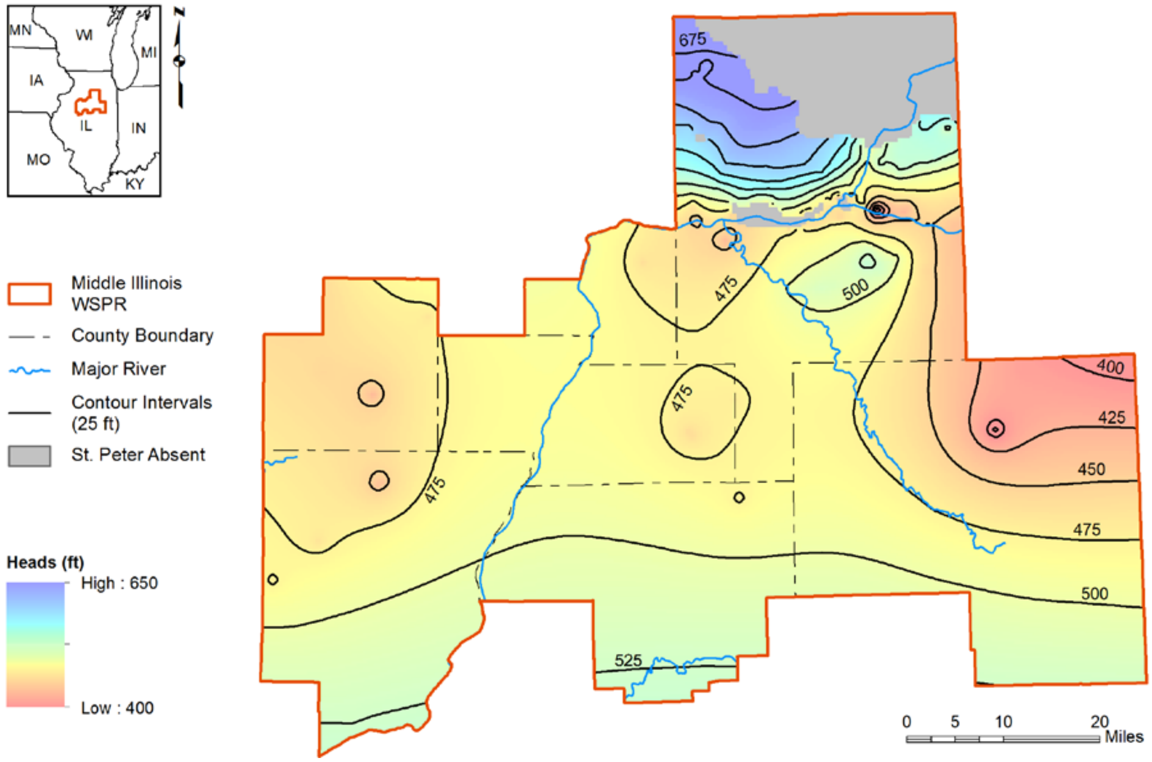


Figure 30. Simulated potentiometric surface of St. Peter Sandstone for 2016

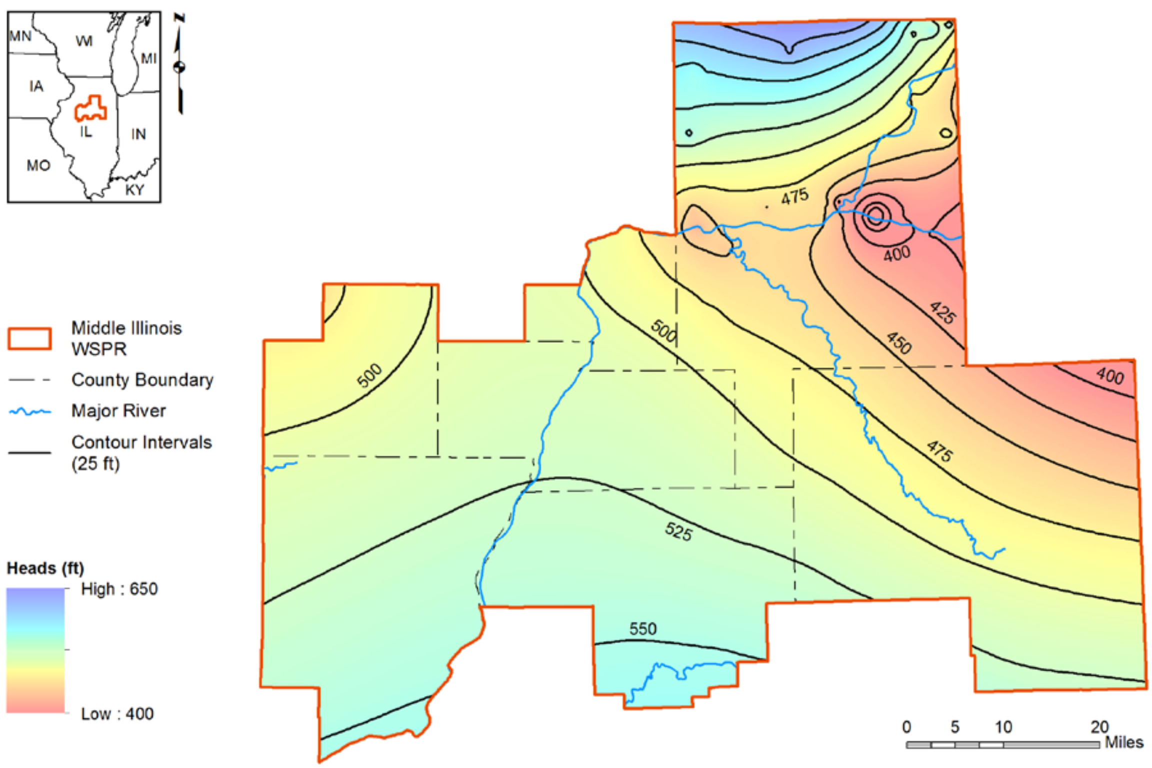


Figure 31. Simulated potentiometric surface of Ironton-Galesville Sandstone for 2016

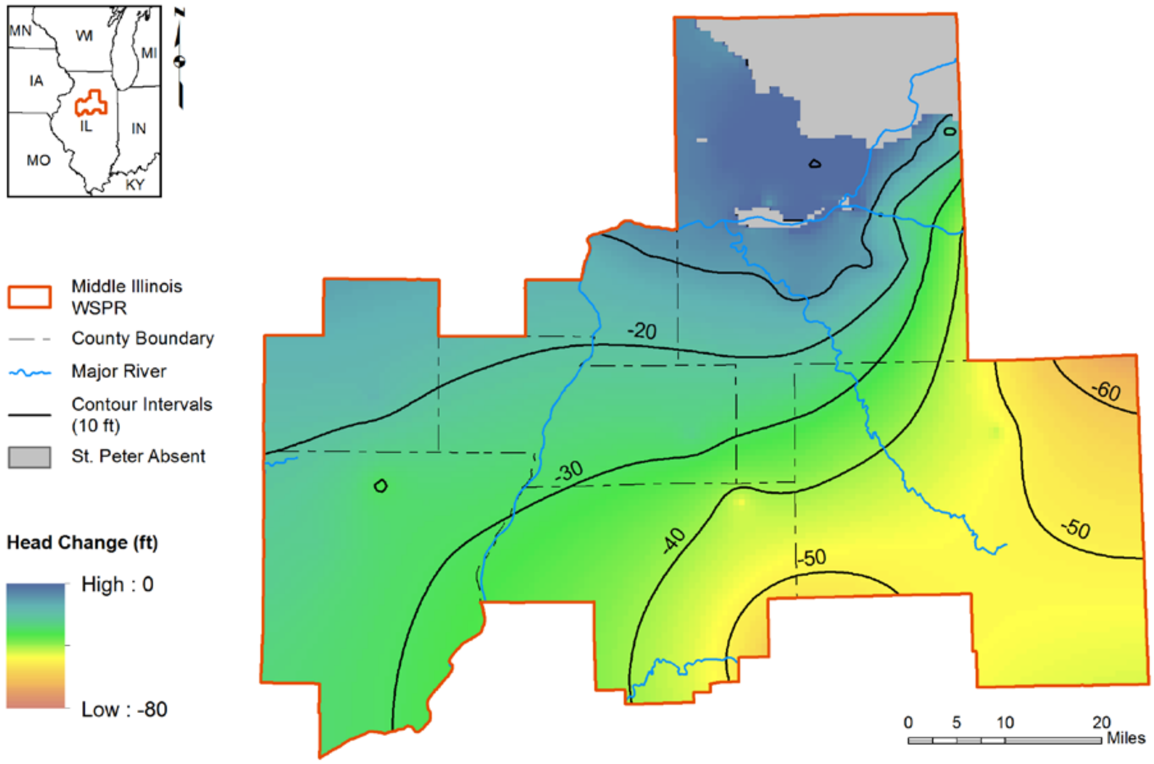


Figure 32. Simulated head change from 2016 to 2060 of the St. Peter Sandstone, CT Scenario

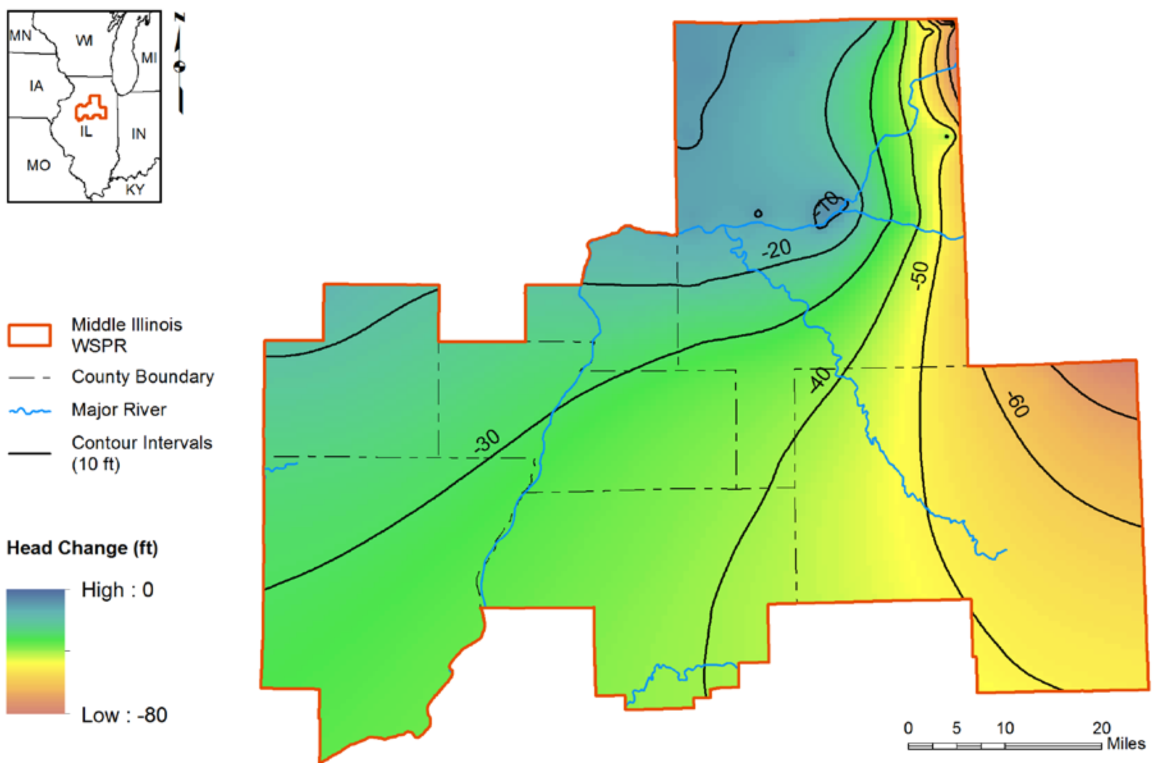


Figure 33. Simulated head change from 2016 to 2060 of the Ironton-Galesville Sandstone, CT Scenario

### 3.7.1 *Water Quality*

Groundwater quality data discussed in this section come from the ISWS Groundwater Quality Database and a sampling program in 2015. We collected samples from 21 wells open to the St. Peter Sandstone in the Illinois River WSPR. These were primarily public supply wells, but also included a few commercial and domestic wells. Sample procedures and a summary of the results are found in Appendix A.

Most of the bedrock wells have relatively high TDS concentrations, greater than the secondary drinking water limit of 500 mg/L. Water in the bedrock aquifers is old, having migrated through the subsurface for tens of thousands of years. The longer that water is in contact with rocks and sediments, the higher the TDS levels tend to be. LaSalle County is the exception, having much lower TDS values than the rest of the region on account of the shallower nature of the aquifers there and thus much younger water.

Because of the high TDS levels, many elements and aqueous species have elevated concentrations. As the TDS levels increase, chloride and sodium become the dominant ions in the water; this is a natural phenomenon which is also true of seawater and brines. Chloride's secondary drinking water standard of 250 mg/L is exceeded in some of the bedrock wells in the region (Figure 34). There are several other elements with concentrations approaching or exceeding drinking water standards, including fluoride and radium (Figure 35 and Figure 36, respectively). These contaminants are all produced naturally within the aquifers. Fluoride has both a primary (enforceable) standard (4 mg/L) and a secondary standard (2 mg/L). The primary standard for total radium is 5 picoCuries/L (pCi/L). The use of these bedrock aquifers as drinking water sources requires treatment to meet the drinking water quality regulations.

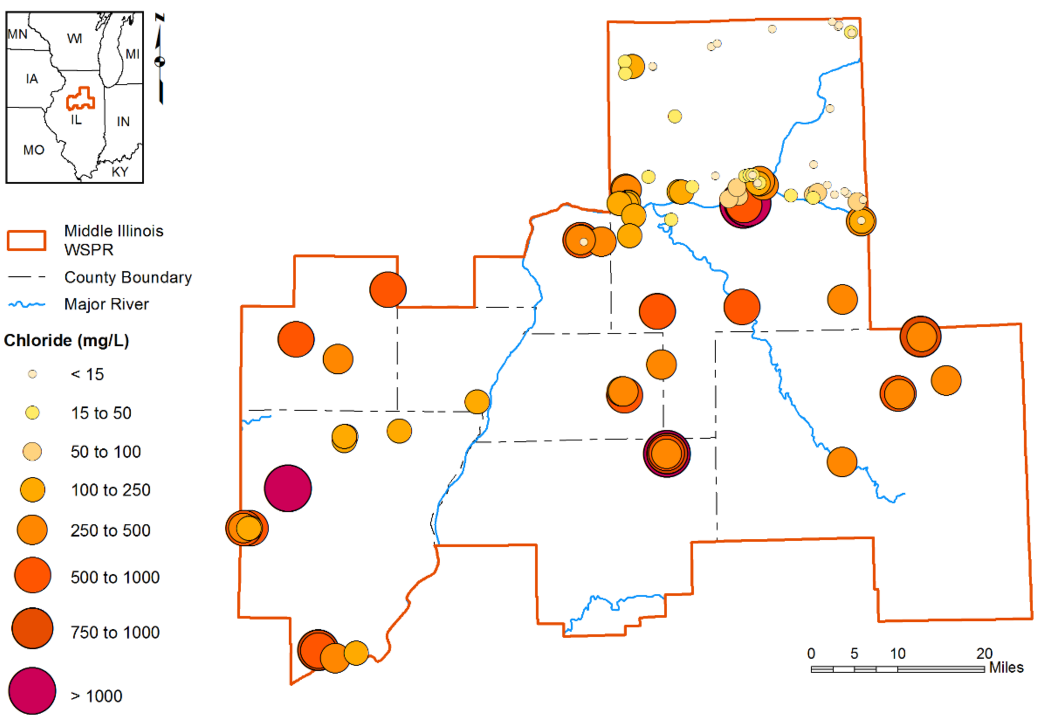


Figure 34. Chloride concentrations in in Cambrian-Ordovician sandstone aquifers in the Middle Illinois Region. The secondary drinking water standard is 250 mg/L.

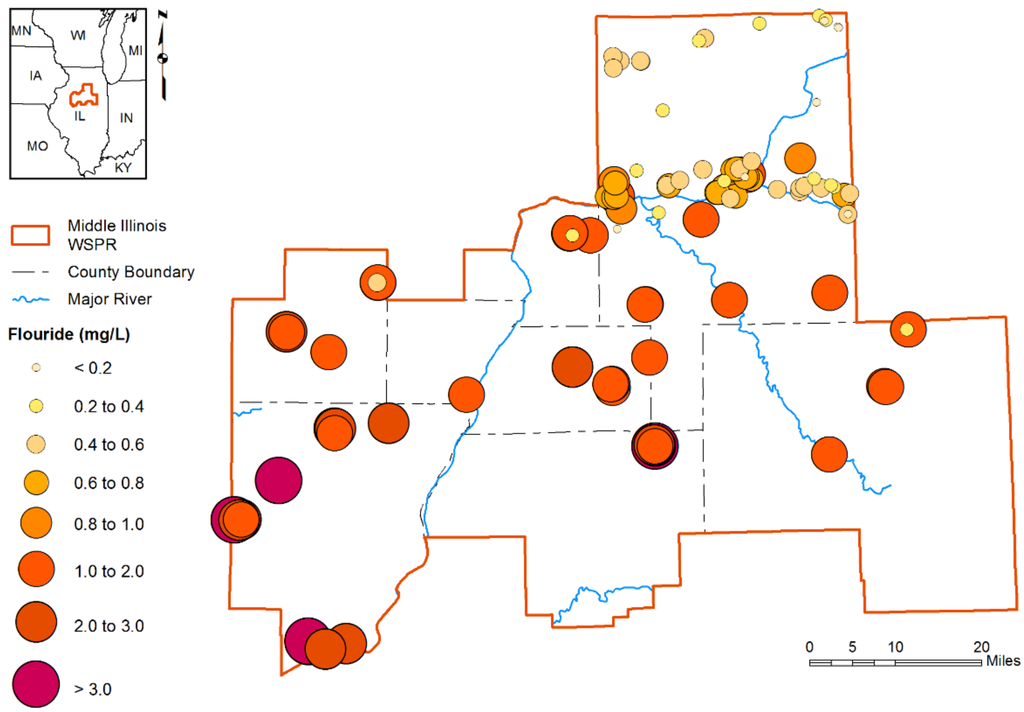


Figure 35. Fluoride concentrations in Cambrian-Ordovician sandstone aquifers in the Middle Illinois Region. The primary drinking water standard is 4 mg/L.

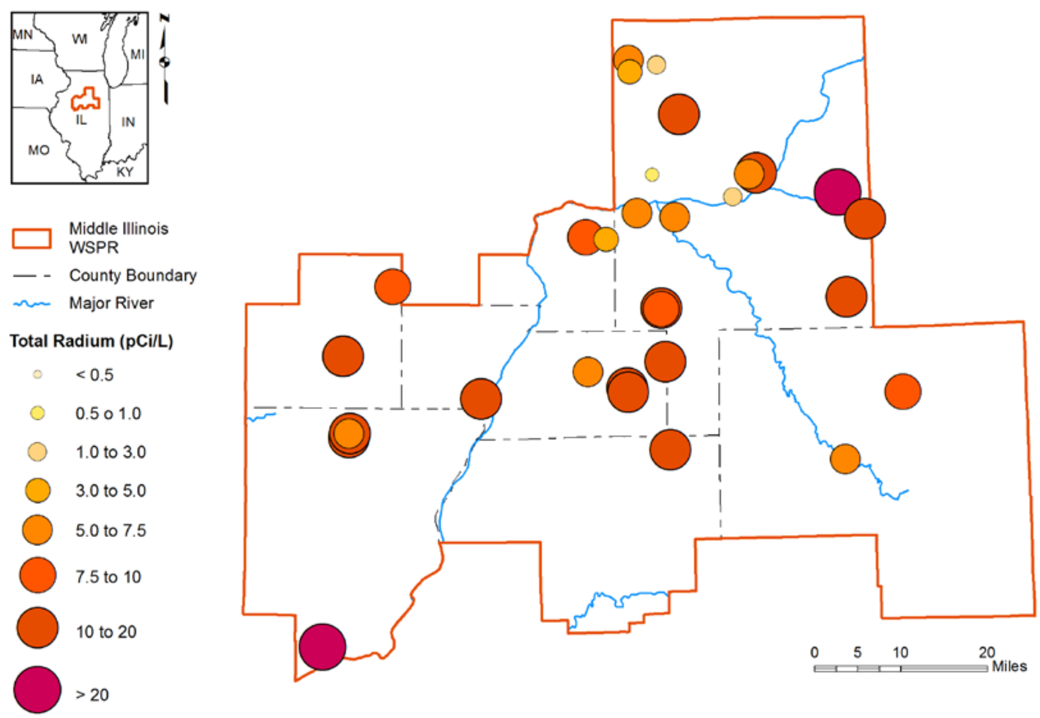


Figure 36. Total radium concentrations in Cambrian-Ordovician sandstone aquifers in the Middle Illinois Region. The drinking water standard is 5 pCi/L.

## 3.8 Groundwater Risks

### *3.8.1 Risks to Sand and Gravel Supplies*

Using model simulations, we identified the areas with the largest head declines in the shallow aquifers between now and 2060 using the CT scenario (Figure 20). These include Washburn, Low Point Water District, Benson, Secor, El Paso, Peoria, Peoria Heights, and associated industries. These declines do not necessarily mean that the unconsolidated materials will no longer be useable, but there may be a need for nearby shallow wells (public supply, industrial, or residential) to be drilled deeper as the shallow potentiometric surface declines.

Since the CT scenario includes minimal growth or even declines in demands for multiple facilities, it is important to also examine risk in a more qualitative manner given current conditions. In other words, which areas might be at risk if demands unexpectedly increase? To this end, we compared the transmissivity T ($ft^2/d$) of the aquifer underlying each municipality with the total demands Q ($ft^3/d$), weighted by the area A ($ft^2$) of the municipality using the following formula:

$$Risk = \frac{Q * A}{T}$$

This qualitative metric allows us to rank facilities by the stress that additional demands from sand and gravel aquifers would place on their water supply (Figure 37). Most of these facilities are small, pumping out of local sands and gravels that, according to the model transmissivity map of the region, are not very productive. The city of LaSalle is the exception; almost all demands from LaSalle are satisfied from the small portion of the sands and gravels along the Illinois River that intersects their municipal boundary (Figure 14).

Where the unconsolidated aquifers are at the land surface, recharge often limits drawdown, minimizing water supply issues. However, this also makes many municipalities more susceptible to anthropogenic contamination, such as nitrate from fertilizer (Figure 22), chloride from road salt (Figure 23), and volatile organic compounds. Figure 38 depicts communities that may be sensitive to contamination, which not surprisingly are located along the Illinois River.

Of particular concern are those communities that are sensitive to both future water demands (Figure 37) and water quality (Figure 38) concerns. LaSalle and Sparland both fall in this category. Since both pump water in a local sand, if that sand were to become contaminated, there would be few or no options to drill other shallow wells within their municipality. These communities would most likely be forced to drill sandstone wells or purchase water from a nearby community.

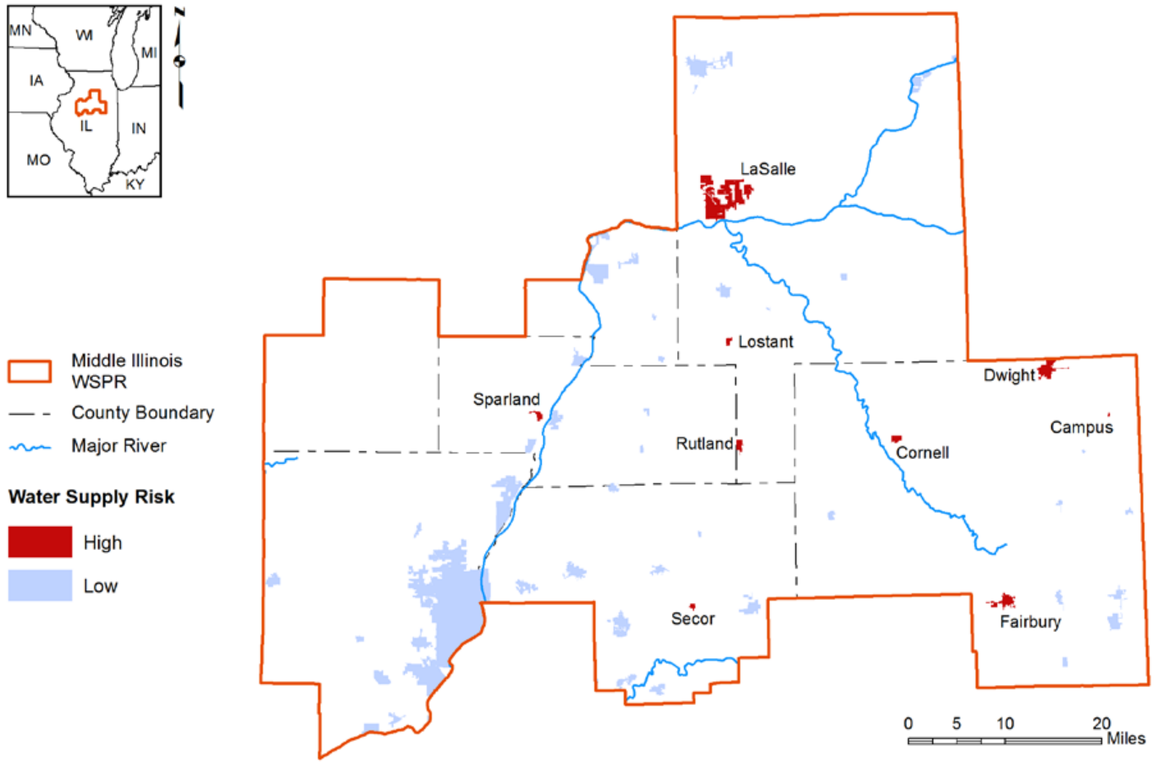


Figure 37. Risk to public supply systems reliant on sand and gravel aquifers based on local transmissivity

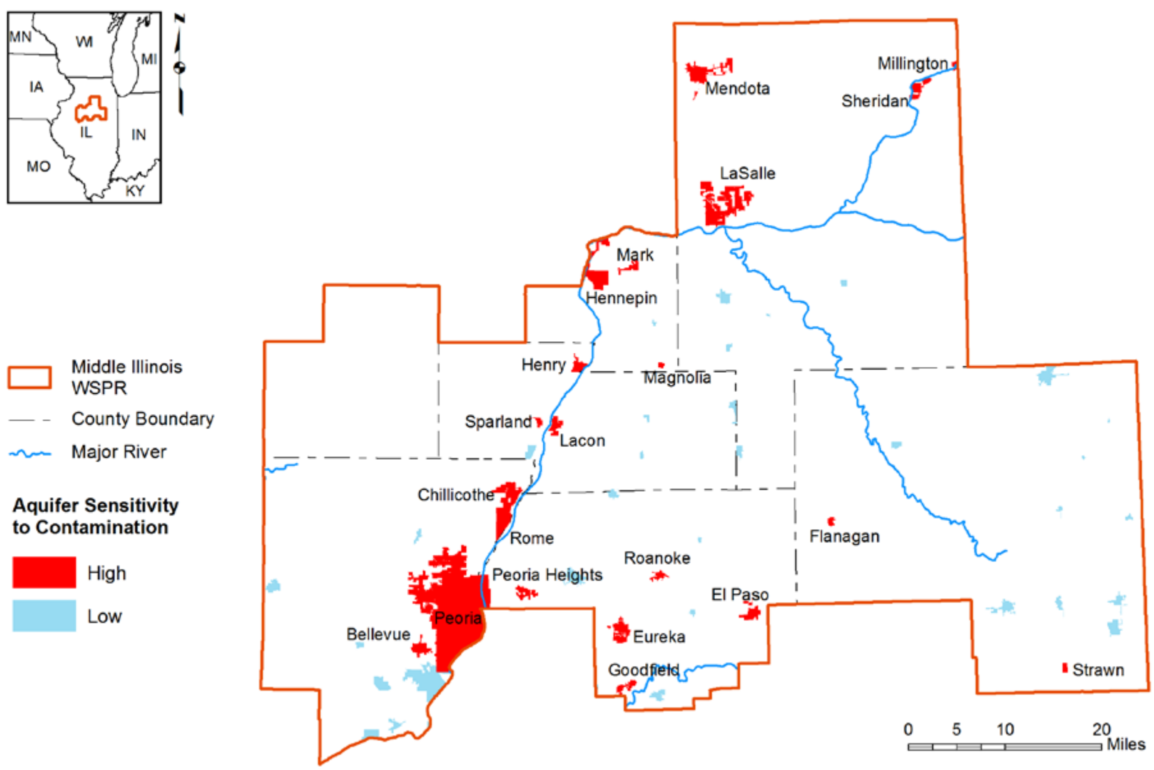


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Figure 38. Sensitivity to aquifer contamination, determined by proximity of a municipality to a highly recharged area

### *3.8.2 Sandstone Aquifers*

Head declines in both the St. Peter and Ironton-Galesville are much greater and more widespread than shallow groundwater declines simulated in the CT scenario, owing to the comparatively low transmissivity of these sandstones. However, respectively large head declines are not necessarily correlated with risk to the sandstone. For sandstone wells, particularly those drilled deep, the risk generally manifests as water quantity or quality issues when the sandstone starts to desaturate. The uppermost St. Peter Sandstone is generally the first to experience desaturation.

Risk to the sandstone aquifers was determined for both current conditions as determined by data from 2014 and future conditions by superimposing simulated drawdown from 2014 conditions to 2060. The threshold for risk is based on available head above the top of the aquifer. Only areas with at least a 50 percent decline in available head since predevelopment are considered; where the sandstone aquifers are near the surface, heads may be near the top of the aquifer under natural conditions. The risk threshold for the two aquifers differs based on well construction trends and expected impacts:

1. The St. Peter Sandstone is considered at risk where the available head is less than 200 feet, as this is a typical drawdown for a high-capacity well completed in only the St. Peter Sandstone. As the St. Peter Sandstone is increasingly used as a supply for domestic wells, any dewatering of the St. Peter Sandstone is also likely to cause domestic wells to go dry.
2. The Ironton-Galesville Sandstone is considered at risk where the available head is less than 550 feet. Below this threshold is unprecedented territory. The main consideration for risk is the extreme entrance velocities that can undermine the Ironton-Galesville Sandstone and damage pumps. Drawdown of up to 400 feet has been observed in wells completed in the Ironton-Galesville Sandstone, and available head should be maintained above the aquifer to continue using it as a sustainable supply. We conservatively add an additional 150 feet above the top of the Ironton-Galesville when establishing risk because declines below this are unprecedented, so new issues may be encountered that have not previously been observed with such extreme conditions.

Groundwater demands along the Illinois River in eastern LaSalle County, coupled with growth in demands in Grundy and Will Counties, currently result in the risk of desaturation of the uppermost St. Peter Sandstone (Figure 39). Future growth in these areas will expand this risk zone, as indicated by the CT scenario in Figure 39. The existing industries at risk along the Illinois River are not expected to increase demands much by 2060. However, new industrial growth might put additional stress on water supply in this region, which is not simulated in our CT scenario. Notably, the geology in this area drives the risk. Demands along the Illinois River in western LaSalle County and the rest of the Middle Illinois WSPR are expected to have less of an adverse impact on groundwater availability since the St. Peter is physically deeper, requiring more drawdown to put the aquifer at risk.

A repeated analysis of risk in the Ironton-Galesville indicated no current or future risk zones; that is to say, the available head did not fall by more than 50 percent since predevelopment. This lack of risk is because of the relatively small demands from this unit and the larger available head in predevelopment compared to the St. Peter.

In the near future, many communities in northeastern Illinois may switch sources from the sandstone aquifers to surface water. Many communities and industries in Cook and DuPage Counties switched from the sandstone aquifers to Lake Michigan water in the 1980s and 1990s, which caused large head increases in those counties between 1980 and 2014 (Figure 27). Currently, many communities in Will, Kendall, and Grundy Counties are engaged in discussions regarding a switch to alternative supplies. Whether this would be a complete switch away from groundwater or if some wells would remain active is uncertain. Model simulations have indicated that areas near the center of the cone of depression (Figure 26) will not be able to withstand additional demands beyond a few Mgd, so some change is likely before 2060. As a result, the future demand scenarios shown in this report outside of the Middle Illinois WSPR should be viewed as a worst-case scenario. As the water use plans for northeastern Illinois change, these future scenarios will be updated. This will certainly impact model results and associated risk zones in eastern LaSalle County, although the impact to the central portion of the county where the Illinois River remains an important factor in groundwater heads is less certain.

Note that the expected new demands in Bloomington that led to a simulated 50 foot decline in the southern part of Middle Illinois do not appear to be great enough to put the region at risk. The reason is that the available head remains above 50 percent in this region, primarily due to the depth of the St. Peter.

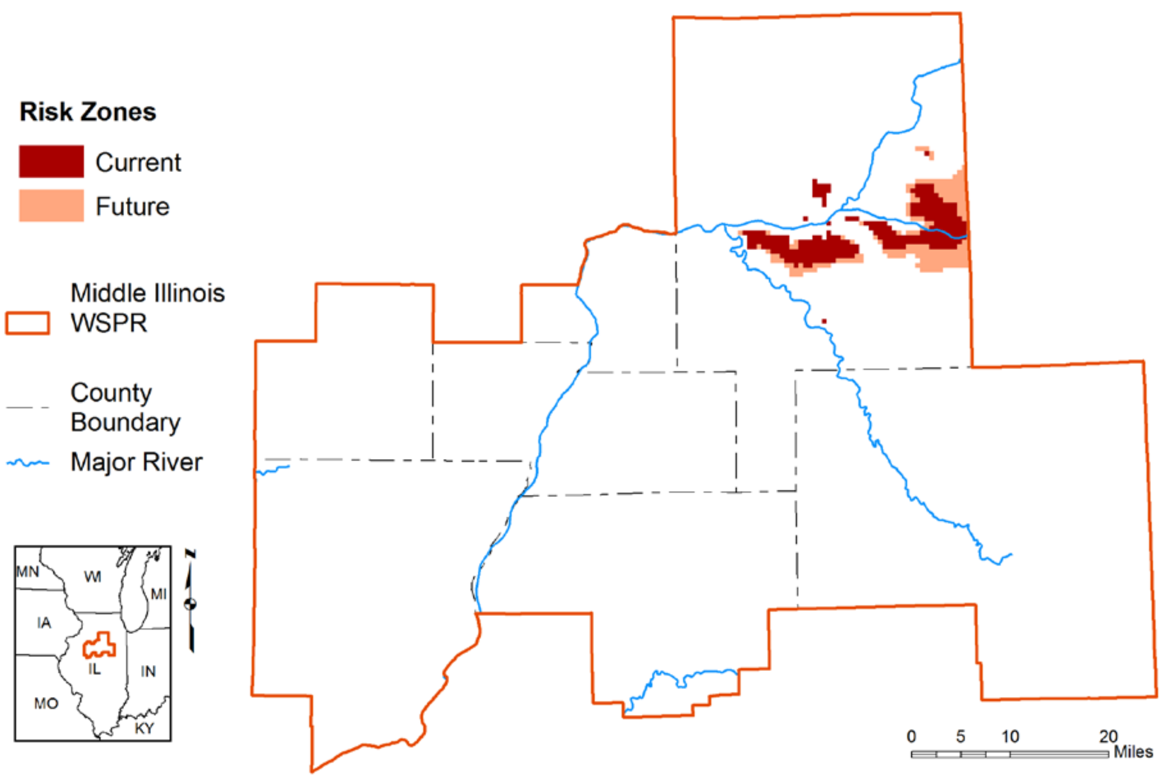


Figure 39. Risk to the sandstone in Middle Illinois based on the 2060 CT scenario

### 3.8.3 Single Supply Risk

Many public facilities have only a single well. This has historically been problematic, most recently in the Middle Illinois WSPR at Cedar Point, where a sandstone well drilled in 1912 failed in 2017 and a replacement well was not ready for three months. Table 8 shows all public facilities in the region with a single well and the year that the well was drilled. It should be noted that this table was developed from the IWIP database of withdrawals, focusing specifically on wells that have reported some withdrawals since 2005. In some cases, a facility may have an emergency well, but if the ISWS does not have a record of this well having pumped even a small amount of water for 10 years, we assume it to be non-functional.

Table 8. Public Facilities with Only One Well with Reported IWIP Withdrawals Since 2005 that do not Purchase Water from Another Source

| IEPA ID | Facility Name | County | Year Drilled |
|---|---|---|---:|
| IL1430080 | Buffalo Hollow Farms Water Assn | Peoria | unknown |
| IL1235100 | Camp Grove | Marshall | 1965 |
| IL0995040 | Cedar Point | LaSalle | 2017 |
| IL0995225 | Dattis MHP | LaSalle | 1958 |
| IL1435150 | Edelstein Water Coop | Peoria | 1965 |
| IL0995110 | Four Lakes Subdivision | LaSalle | 1974 |
| IL0990060 | Four-Star Campground | LaSalle | 1974 |
| IL1435750 | Fox Creek Farms Water Co | Peoria | 1971 |
| IL1235150 | Hopewell | Marshall | 1977 |
| IL0990020 | Jons MHP | LaSalle | 1994 |
| IL1750100 | La Fayette | Stark | 1959 |
| IL2035125 | Lake Wildwind MHP | Woodford | 1971 |
| IL0995050 | Land & Water Assn | LaSalle | 1966 |
| IL0990400 | Leonore | LaSalle | 1961 |
| IL0995336 | Lynnwood Water Corp | LaSalle | 1963 |
| IL0990110 | Marseilles South | LaSalle | 1998 |
| IL1550150 | McNabb | Putnam | 1966 |
| IL2035165 | Mill Point MHP | Woodford | 1968 |
| IL2035300 | Oak Ridge Sanitary District | Woodford | 1968 |
| IL1435490 | Santa Fe Estates Water Assn | Peoria | 1978 |
| IL1435600 | Stever Dist Improvement | Peoria | 1938 |
| IL1050700 | Strawn | Livingston | 1933 |
| IL2030010 | Valley View Subdivision | Woodford | unknown |
| IL1230300 | Varna | Marshall | 1980 |
| IL0995425 | Wildlife MHP | LaSalle | unknown |

# 4 Surface Water Studies in Middle Illinois

Surface water sources can be classified as free-flowing streamflow or stored water in reservoirs or lakes. Groundwater is usually preferred for public water supply because groundwater often has superior quality, and surface water may be located farther from communities (Roadcap et al., 2011). However, many public water supplies use surface water when it is available, particularly when large quantities are needed. Streamflow in large rivers such as the Illinois River is generally sufficient for human needs. For rivers and streams that have limited streamflow during drought conditions, free-flowing streamflow may not be a sufficient and reliable water supply source. Water may need to be stored for use during drought or low flow conditions. In some cases, a low-head dam may provide sufficient storage for short periods when the streamflow itself does not meet water demand. Off-channel reservoirs may also be used to augment low-head impoundment storage and free-flowing streamflow. Off-channel storage can also be blended with river water when water quality in the stream is impaired. In cases where streamflow does not meet water demands for an extended period, such as a multi-month drought, a large reservoir that impounds an entire stream valley may be needed to provide a reliable water supply.

## 4.1 Surface Water System

Surface water in the Middle Illinois WSPR is a significant source for several large public supplies and for industrial, navigation, and recreation purposes. The primary surface water sources in the region include the Illinois and Vermilion Rivers (Figure 40). The Illinois River flows from east to west from Dresden Island to Hennepin, then turns south toward Kingston Mines, with a total length of 125 miles in the Middle Illinois WSPR. The major tributaries of the Illinois River in the region include Aux Sable Creek, Fox River, Mazon River, Vermilion River, Big Bureau Creek, Senechwine Creek, and Kickapoo Creek. Although Aux Sable Creek and the Mazon River are mostly outside the seven-county region, they are located within the same HUC8 unit as the Illinois River below the confluence of the Des Plaines and Kankakee Rivers. Furthermore, water availability from these streams has not been examined in previous water supply planning studies and, as a result, Aux Sable Creek and the Mazon River are included in this study. The Fox River lies in a different HUC8 unit and has been studied in the Northeastern Illinois Water Supply Planning project (Meyer et al., 2012) and thus is not included in this study.

The Illinois River is an Illinois "public water," generally defined as a navigable river and open or dedicated to public use, including all bayous, sloughs, backwaters, and submerged lands connected to the main channel or water body during normal flows (Meyer et al., 2012). IDNR generally uses the 7-day, 10-year low flow ($Q_{7,10}$), which is defined as the minimum 7-day average flow with a 10 percent chance of occurring annually (i.e., at a recurrence interval of 10 years), as the protected minimum flow for all Illinois public waters. Except in cases where long-standing surface water withdrawals from public waters are exempt, withdrawals are required to cease when streamflow falls below the designated protected minimum flow or would otherwise cause the streamflow to fall below the designated protected minimum flow. The Illinois River is also a part of the Illinois Waterway, which connects Lake Michigan and the Mississippi River by a system of rivers, lakes, and canals to provide a shipping connection from the Great Lakes to the Gulf of Mexico. A series of locks and dams control flow in the Illinois River to maintain a navigation channel of at least 9 feet deep.

Streamflows in most rivers and streams in the Middle Illinois carry abundant streamflow during normal or wet conditions, but may reach very low levels during a drought, even to the point of drying up completely in some cases. Table 9 shows the observed minimum daily flows at selected USGS streamflow gages for the entire available period of record, with many reported to be zero cubic feet per second (cfs). Big Bureau Creek at Princeton is expected to contain a measureable low flow during drought periods, with some flow reaching the creek by way of the Hennepin Canal. In the absence of pertinent low flow measurements and uncertainty regarding the connection with the canal, the creek is not considered a potential water supply source. The Hennepin Canal is part of the Illinois public waters as well but is not considered a potential water supply source as it relies on an IDNR diversion of water from the Rock River dedicated to maintaining flowing water in the canal.

Table 9. Observed Minimum Daily Flows at Selected USGS Gages For the Available Period of Record

| Site No | Site Name | Observed Minimum Daily Flow (cfs) |
|---|---|---|
| 05542000 | Mazon River near Coal City | 0 |
| 05543500 | Illinois River at Marseilles | 461 |
| 05554000 | North Fork Vermilion River near Charlotte | 0 |
| 05554500 | Vermilion River at Pontiac | 0 |
| 05555300 | Vermilion River near Leonore | 2.6 |
| 05556500 | Big Bureau Creek at Princeton | 0 |
| 05557000 | West Bureau Creek at Wyanet | 0 |
| 05558500 | Crow Creek (West) near Henry | 0 |
| 05559000 | Gimlet Creek at Sparland | 0 |
| 05559500 | Crow Creek near Washburn | 0 |
| 05559700 | Senachwine Creek at Chillicothe | 0 |
| 05561000 | Ackerman Creek at Farmdale | 0 |
| 05568500 | Illinois River at Kingston Mines | 600 |

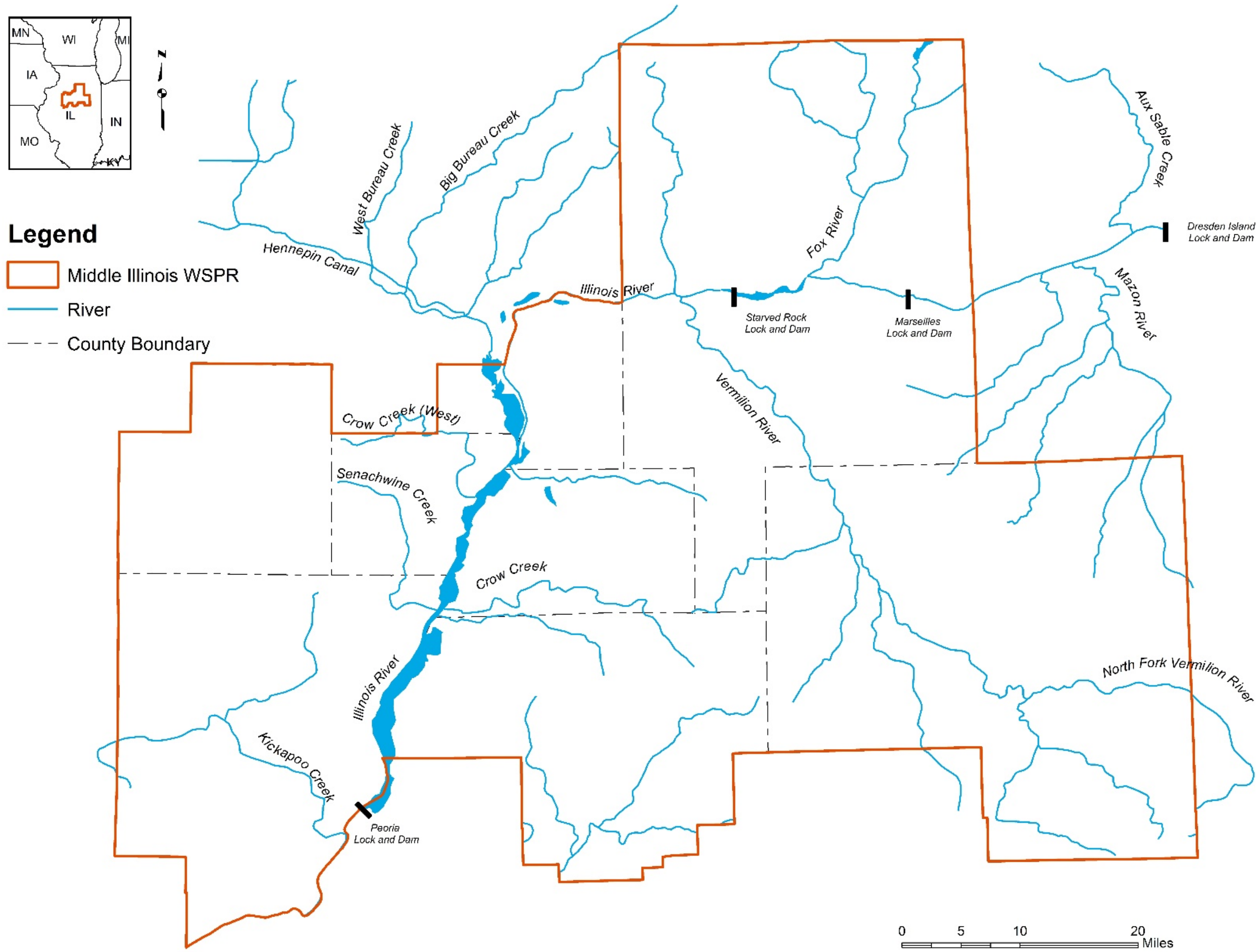


Figure 40. Surface water network in the Middle Illinois WSPR

## 4.2 Surface Water Demand

The primary sectors using surface water in the region include power generation, industry, and public supply systems. Figure 41 shows the surface water withdrawals in the Middle Illinois, and Table 10 shows the water withdrawals by sector. Notably, the Middle Illinois surface water system covers a region that is slightly different from the Middle Illinois WSPR as hydrologic boundaries are used to define the surface water system.

There are 22 surface water withdrawal intakes in Middle Illinois. Six are for thermoelectric power generation, three for public water supply (Peoria, Streator, and Pontiac), seven for industry, and six for agriculture and environmental purposes.

Total surface water withdrawals were 1276.9 Mgd in 2013. It is noted that the surface water system in the Middle Illinois region is not exactly the same as in the seven counties. Note that recirculating water within a facility or with a cooling pond is not included as surface water withdrawals. Most surface water withdrawals in the Middle Illinois are for non-consumptive use by thermoelectric power generation, accounting for 86.3 percent of total withdrawals. Most of the water used in power generation is returned to the surface water system, though at a higher water temperature. The next highest demand is for the industry sector, which accounts for 12.5 percent of withdrawals. Public water supply demand is 1.0 percent and agriculture and environmental water use is 0.2 percent of the total surface water demand.

Eighteen of the 22 surface water withdrawal intakes are in the Illinois River. Streator and Pontiac withdraw 2.01 and 1.88 Mgd, respectively, from the Vermilion River. Three golf courses use a minimal amount of surface water from smaller streams.

Though the majority of surface water use is non-consumptive, i.e., the water is returned to the surface water system, this large water demand can be potentially stressful to surface water systems during droughts and low flow conditions. For example, the 3-day minimum daily flow at the Illinois River at Marseilles is 1450 cfs (937 Mgd), which is greater than only the current water demand by the Exelon Dresden Station (740 cfs or 478.5 Mgd). To make things worse, more water is often needed for cooling purposes during droughts as electricity demand peaks during the hot summer and river water temperatures are relatively higher.

Free-flowing streamflow in the Vermilion River alone does not meet the current water demands for Streator and Pontiac when the flow is low or the river water contains $NO_3$-N concentrations that are higher than the federal drinking water standard of 10 mg/L. Both public water supply systems are augmented by on-site ion exchange systems and off-channel storage.

Table 10. Surface Water Withdrawals in the Middle Illinois for 2013 by Sector

| **Sector** | **Water Withdrawal (Mgd)** | **Percentage** | **Number of Withdrawals** |
|---|---|---|---|
| Agriculture | 2.9 | 0.2 | 6 |
| Industry | 159.0 | 12.5 | 7 |
| Public supply | 12.5 | 1.0 | 3 |
| Power generation* | 1102.6 | 86.3 | 6 |
| Total | 1276.9 | | 22 |

*Exelon LaSalle Generation Station circulation water demand of 1535.7 Mgd from the cooling pond and the Dresden Island Generation Station withdrawals from the cooling pond are not included.

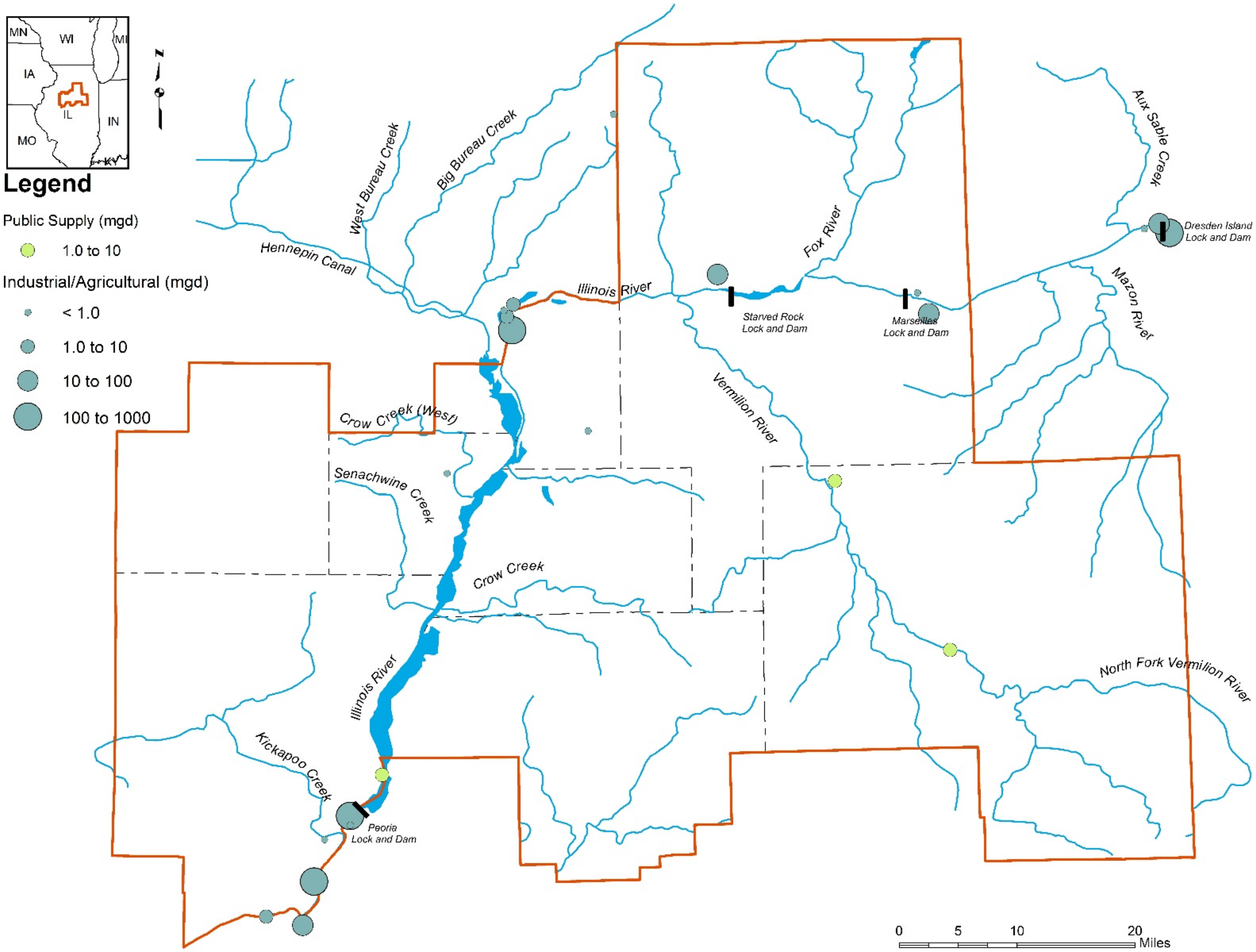


Figure 41. Surface water intakes and withdrawals (Mgd) for public supply, industrial (including power generation), and irrigation water usages

## 4.3 Hydrologic Analysis

### *4.3.1 Available Hydrologic Records*

Long-term continuous gages monitor the streamflow over time and provide important data to understand water supply in the surface water system. Table 11 lists the 19 active and historic USGS continuous streamflow gages in the Middle Illinois and Figure 42 shows the locations of these gages. These gages monitor headwaters to the main stem of the Illinois River, with the drainage areas upstream of the gages ranging from 5.66 to 15,818 square miles. The periods of record range from 7 to 94 years with 14 having at least 20 years of record. Among these 18 continuous gages, nine are currently active, with three on the Illinois River (Marseilles, Henry, and Kingston Mines) and three on the Vermilion River (Charlotte, Pontiac, and Leonore). Long-term continuous streamflow gages are critical for water supply planning, and maintaining their operation is vital for long-term assessment and future planning.

Because operation of many streamflow gages in Illinois started in the late 1930s and early 1940s, a 75-year period (1940-2014) is used as the base period for the Middle Illinois region. This period covers the relatively dry period of the 1950s and the relatively wet period of post-1970. This base period is representative of long-term records and comparable among different gages. For gages having shorter periods of record, a record extension technique developed by the ISWS was employed to estimate hydrologic indices that are representative of the expected flow frequency characteristics for the entire base period (Knapp and Russell, 2004).

Table 11. Continuous USGS Streamflow Gages in the Middle Illinois and Pertinent Information

| Site No | Site Name | Drainage Area (sq mi) | Record Length (years) | Record Start | Record End |
|---|---|---|---|---|---|
| **05541710** | Aux Sable Creek Near Morris | 172 | 7 | 3/16/2007 | present |
| **05542000** | Mazon River Near Coal City | 455 | 73 | 10/1/1939 | present |
| **05543500** | Illinois River At Marseilles | 8,259 | 94 | 10/1/1919 | present |
| **05554000** | North Fork Vermilion River Near Charlotte | 186 | 19 | 10/1/1942 | 9/30/1962 |
| **05554500** | Vermilion River At Pontiac | 579 | 71 | 10/1/1942 | present |
| **05555300** | Vermilion River Near Leonore | 1,251 | 83 | 5/8/1931 | present |
| **05556500** | Big Bureau Creek At Princeton | 196 | 78 | 3/1/1936 | present |
| **05557000** | West Bureau Creek At Wyanet | 86.7 | 30 | 3/1/1936 | 9/30/1966 |
| **05557500** | East Bureau Creek near Bureau, IL | 99.0 | 30 | 4/1/1936 | 9/30/1966 |
| **05558000** | Big Bureau Creek At Bureau | 485 | 11 | 10/1/1940 | 9/29/1951 |
| **05558300** | Illinois River At Henry | 13,544 | 32 | 10/1/1981 | present |
| **05558500** | Crow Creek (West) Near Henry | 56.2 | 22 | 5/13/1949 | 10/1/1971 |
| **05559000** | Gimlet Creek At Sparland | 5.66 | 25 | 10/1/1945 | 9/30/1971 |
| **05559500** | Crow Creek Near Washburn | 115 | 26 | 10/1/1944 | 10/1/1971 |
| **05559700** | Senachwine Creek At Chillicothe | 84.5 | 5 | 12/2/2007 | present |
| **05561000** | Ackerman Creek At Farmdale | 11.2 | 26 | 12/1/1953 | 9/30/1980 |
| **05563000** | Kickapoo Creek Near Kickapoo | 119 | 17 | 10/1/1944 | 9/30/1962 |
| **05563500** | Kickapoo Creek At Peoria | 297 | 29 | 3/24/1942 | 9/30/1971 |
| **05568500** | Illinois River At Kingston Mines | 15,818 | 74 | 10/1/1939 | present |

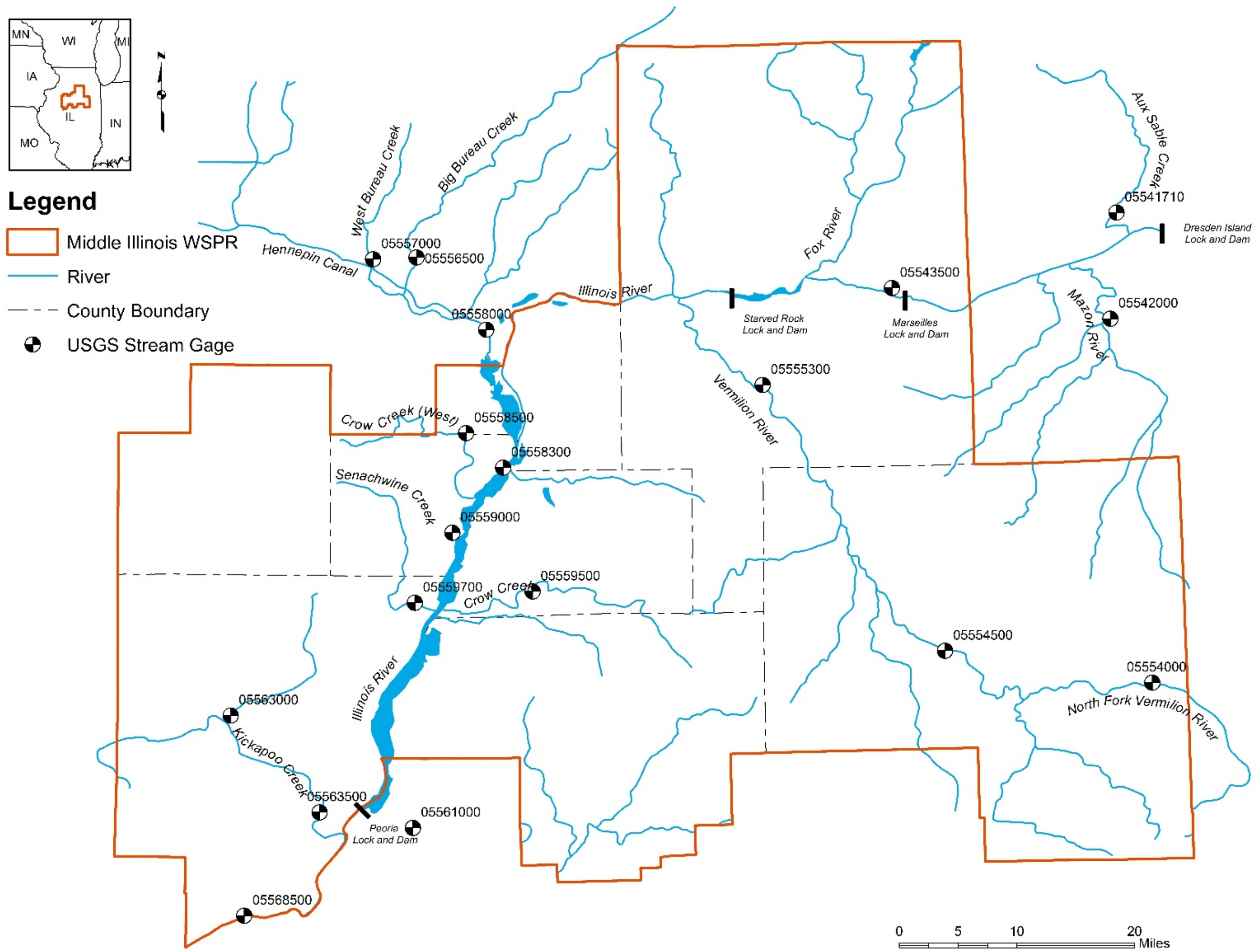


Figure 42. Locations of the continuous USGS streamflow gages in the Middle Illinois Region

### *4.3.2 Changes in Illinois River Low Flows*

For nearly 60 years, from the late 1930s to the mid-1990s, low flows on the Illinois River remained relatively unchanged. During this period, the annual 7-day low flow at the Marseilles USGS gage averaged roughly 4,000 cfs, and the 10-year low flow for these years was an estimated 3,200 cfs. The lowest observed flow conditions during this period occurred in two drought years, 1940 and 1963, which had 7-day low flows of 2,570 and 2,694 cfs, respectively. Although the Kankakee River normally provides the largest source of flow in the upper Illinois River, the Chicago Sanitary and Ship Canal (CSSC) is the dominant source of water during the lowest flow conditions.

In the 1990s, two changes occurred that have since caused significant reductions in low flows from the CSSC. The first change was a reduction in Chicago's water usage, which has since greatly diminished effluent discharges to the CSSC. Effluent discharges to the CSSC during the lowest flow periods are now about 40 percent less than they were roughly 20 years ago. The second change was the elimination of discretionary diversions from Lake Michigan during the cool season (October through March). The primary purpose for these discretionary flows was to maintain water quality standards in the CSSC; however, ongoing improvements to wastewater treatment made these flows unnecessary at lower water temperatures. Communication with IDNR indicated that discretionary water quality diversions during the warm season will also be lessened or discontinued in the near future. Although this has yet to occur, such a change could additionally affect low flows in the CSSC.

Since 1998, the average annual low flow in the Illinois River at Marseilles has been reduced to 3000 cfs. The 7-day low flow in eight of those years has been below 2400 cfs; i.e., lower than in any previous year from 1900 to 1998. The two lowest 7-day flows observed at Marseilles occurred during the droughts of 2005 (1,670 cfs) and 2012 (1,680 cfs) (Table 12). With the ongoing reductions in Chicago's water use and effluent discharges, the ISWS estimates that the 2005 drought conditions would today result in a low flow of about 1570 cfs. If discretionary diversions are to be eliminated entirely (i.e., also during the warm season), the ISWS estimates that the lowest flows in the Illinois Waterway will be reduced by an additional 100 cfs, if not more.

Immediately upstream of the Marseilles Dam, the Illinois River splits into two channels. The Marseilles Dam and outflow control structures are located in the larger northern channel, whereas the navigation locks are located at the western end of the smaller southern channel. Because the USGS gage at Marseilles is located in the northern channel, its discharge measurements and historical flow records do not appear to have fully captured the flow that passes through the navigation locks, thus at times under-representing the composite flow of the Illinois River. The additional daily volume of flow that is released through the navigation locks can be calculated by multiplying (1) the daily number of downstream lockage; (2) the dimensions of the lock (110 feet wide and 700 feet long); and (3) the average height or elevation difference between the pools immediately upstream and downstream of the lock, usually a height difference of about 25 feet. During normal or high flow conditions, the water that is released through the navigation locks is comparatively small to the flow in the northern channel and would not substantially change the flow calculation for the river. But during very low flow conditions, the water released through the lock can be as much as 10 percent of the composite flow of the river. Lockage data from the USACE is typically not available by day; therefore, monthly lockage data for selected years were used for this study. During the low flow event of early October 2012, the USACE lockage data indicate that there was an average of six downstream lockages per day at the Marseilles Lock, with a corresponding average flow release of roughly 140 cfs. Thus the 2012 composite 7-day low flow for the Illinois River at Marseilles, including both the northern and southern channels of the river, is calculated to be 1820 cfs, and not the 1680 cfs reported for the Marseilles gage alone. To our knowledge, all prior reports and estimates of low flows at the Marseilles gage by the ISWS and other agencies have neglected to add the extra lockage flow through the southern channel. As illustrated in Table 12, we recommend herein that ISWS low flow estimates for the Marseilles gage be adjusted to account for the flow through the Marseilles Lock, and, lacking specific lockage data for each historical year, suggest that 140 cfs appears to be an appropriate amount for this adjustment.

Table 12. ISWS Estimates of the 7-day, 10-year Low Flow (Q7,10) and Observed 7-day Low Flows at Marseilles in Recent Years

| **Observed 7-day Low Flows** | | | **Estimated 7-day, 10-year low flow ($Q_{7,10}$)** | | |
|---|---|---|---|---|---|
| Year | **Flow (cfs)** | **Adjusted flow (cfs)** | **Year** | **$Q_{7,10}$ (cfs)** | **Adjusted $Q_{7,10}$ (cfs)** |
| **1998** | 1,990 | 2,130 | 1970 | 3,240 | 3,380 |
| **1999** | 1,990 | 2,130 | 1980 | 3,200 | 3,340 |
| **2002** | 2,320 | 2,460 | 1990 | 3,185 | 3,325 |
| **2003** | 2,370 | 2,510 | 2001 | 1,990 | 2,130 |
| **2005** | 1,670 | 1,810 | 2015* | 1,670 | 1,810 |
| **2010** | 2,179 | 2,319 | Near future* | 1,570 | 1,710 |
| **2012** | 1,680 | 1,820 | | | |
| **2013** | 2,154 | 2,294 | | | |

* designates recent unpublished estimates

Given that the 7-day low flows at the USGS Marseilles gage have been reduced by roughly 1500 cfs since 1998 (Table 12), it would be reasonable to assume that a similar reduction has also occurred at the Illinois River locations downstream of Marseilles. However, such corresponding low flow reductions have not been observed in the USGS records downstream (at Kingston Mines and Valley City). The USGS record over the past 20 years at the Kingston Mines gage, located 13 miles downstream of the Peoria Lock and Dam, includes just two 7-day low flow periods of less than 3000 cfs, specifically 2958 cfs in October 2005 and 2960 cfs in October-November 2002. A 1-day estimated low flow of 600 cfs was registered for October 26, 1997, caused by regulation at the Peoria Dam, but no other day in 1997 registered less than 3900 cfs. It would be reasonable to assume that the 7-day, 10-year flow for these past 20 years would be essentially no different from the 3000 cfs estimated using the first 45 years of record at the Kingston Mines gage (Singh et al., 1988).

Notably, Illinois River flows downstream of Peoria can be significantly modified by the huge amount of water that is stored in Peoria Lake and other backwater lakes located between Peoria and LaSalle-Peru. The Upper and Lower Peoria Lakes and the eight largest backwater lakes in Putnam and Marshall Counties have a combined surface area of approximately 32,000 acres (IDNR, 1998). The 16,000 acre-feet of water stored within a 0.5 foot normal operating range of the Peoria pool is sufficient alone to sustain a river flow of 1100 cfs over 7 days. Additional storage along this reach of the Illinois River may be provided by other smaller backwater lakes, wetlands, and bank storage; stored water within the normal operating range could potentially buffer the effects of low upstream inflows.

A closer inspection of the USGS historical flow record at Kingston Mines and the USACE records at the Peoria Dam indicates that the lowest outflows at the Peoria Dam (and those observed at Kingston Mines) do not necessarily correspond to the periods of minimum inflow from upstream. Instead, low flows downstream occur when the stage (and storage) of the Peoria pool has been allowed to fall below its normal operating range and the USACE purposely restricts outflow to increase storage and bring the Peoria pool back to its normal range. Consistent with the Marseilles pool hydraulic simulation analysis and findings presented later in Section 4.6.3, it seems reasonably possible that the frequency and severity of some of the most restricted outflow conditions at the lock and dams could be mitigated by (1) shrinking the operating range of the Illinois River pools during drought and low flow conditions (with a target of operating in the upper half of the normal operational pool) and (2) permitting an incremental increase in the release rate in those periods when a low pool must be increased. As compared to free-flowing rivers, the perceived importance of sustaining higher low flow amounts in a controlled-pool environment such as the Illinois River should merit future consideration. Ultimately, USACE decisions on outflow releases during low pool conditions will be the determining factor in assessing Illinois River low flow frequencies at the southern end of the Middle Illinois study region.

Finally, an inspection of the USGS and USACE records also identifies noticeable differences between the computed outflow for Peoria Dam and the observed flow at Kingston Mines during periods of low flow, more so than would normally be expected between records of these types. The USACE's computed daily outflow for the Peoria Dam includes two notably low 7-day periods over the past 20 years, specifically 7-day average flows of 1526 cfs in October 2012 and 1823 cfs in October-November 2005, which are markedly lower than the corresponding USGS flow estimates. The USGS estimates are believed to be influenced by river stages established downstream at the LaGrange Dam, but the degree of this influence cannot be determined without more detailed data and study. As a result, at this time we feel the existing records may not be sufficient to correctly evaluate low flow frequencies for this portion of the Illinois River. Because low discharges do not always correspond with low stages downstream of the Illinois River dams, acoustic metering may be needed to accurately depict low flow amounts.

Climate and Hydrology Variability

The main driving forces for streamflow are the magnitude, intensity, and timing of precipitation (Stagnitta et al., 2018, Zhang, 2017). Long-term climatic and hydrologic records in the Middle Illinois show considerable climate variability and the resulting hydrologic variability. Figure 43 shows the annual average precipitation and streamflow and corresponding 10-year moving averages for the Illinois River. The precipitation records are for Illinois Climate Division 4, which covers most counties of the study area (Marshall, Peoria, Stark, and Woodford). The hydrology records are from the USGS gage at the Illinois River at Kingston Mines. More than 20 percent of the reported streamflow for Kingston Mines is diverted water from Lake Michigan, and thus the Figure 43 streamflow values reported in inches are greater than the actual annual runoff from the Illinois River watershed. The annual streamflow is reported in inches and expressed as the depth of water spread uniformly over the entire watershed. Figure 43 shows that both precipitation and streamflow increased from 1965 to 1970 and have remained consistently high since 1975. The wet period after 1970 is part of multi-decadal climatic and hydrologic variability (Knapp, 2005). Precipitation and streamflow are closely related; the correlation between annual precipitation and streamflow is 0.77, and the correlation between the 10-year moving average precipitation and streamflow is 0.86.

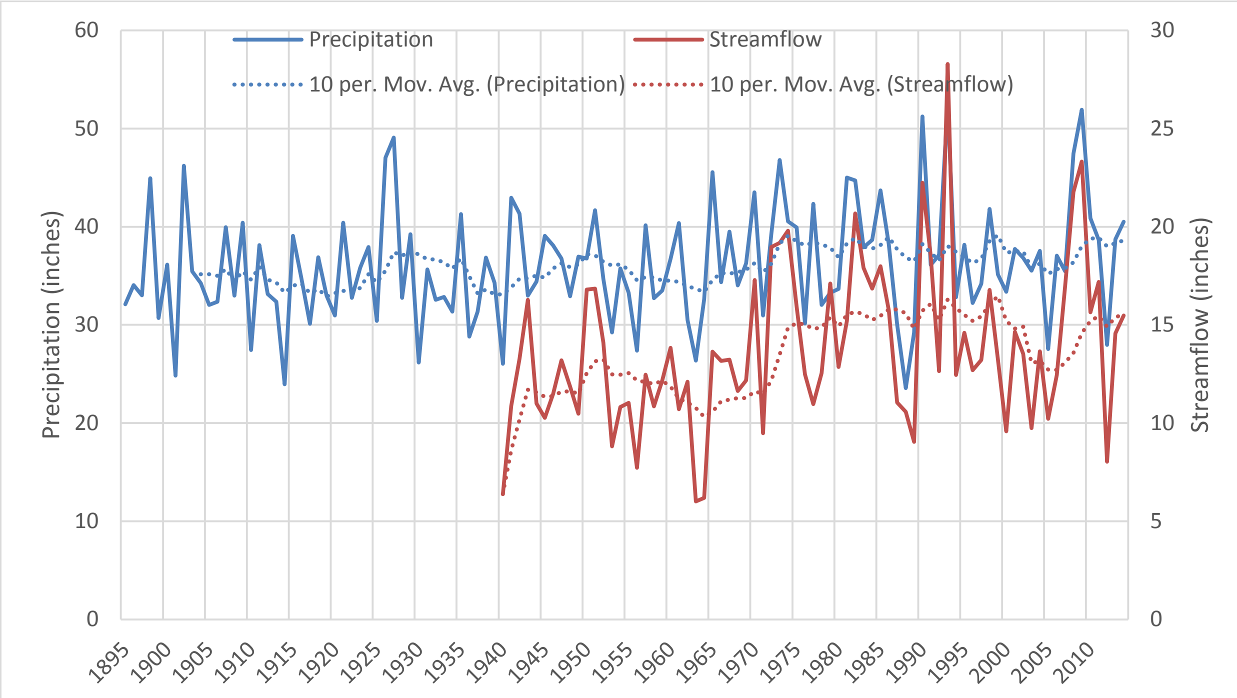


Figure 43. Annual precipitation (blue line) in Illinois Climate Division 4 and streamflow (red line) for the Illinois River at Kingston Mines. Dotted lines are 10-year moving averages.

The streamflow of the Illinois River at Kingston Mines represents the cumulative hydrology response upstream, which includes areas beyond the Middle Illinois WSPR, such as the Des Plaines, Kankakee, and Fox River watersheds and the Lake Michigan diversion and wastewater effluent, which has a major impact on streamflow in the Illinois River. To characterize the local climate and hydrology of just the Middle Illinois WSPR, the climate and hydrology records of the Vermilion River watershed were analyzed. Figure 44 shows the comparison of annual and 10-year moving average precipitation and streamflow data in the Vermilion River watershed. The precipitation record is for Illinois Climate Division 5, which covers most of the Vermilion River watershed, and is used as a surrogate to represent local climate conditions. The streamflow records are for the USGS gage at the Vermilion River at Leonore. The pattern is similar to that observed for the Illinois River upstream of Kingston Mines, and precipitation and streamflow are consistently high after 1970. Precipitation and streamflow are closely related as the correlation between annual precipitation and streamflow is 0.78, and the correlation between 10-year moving average precipitation and streamflow is 0.90.

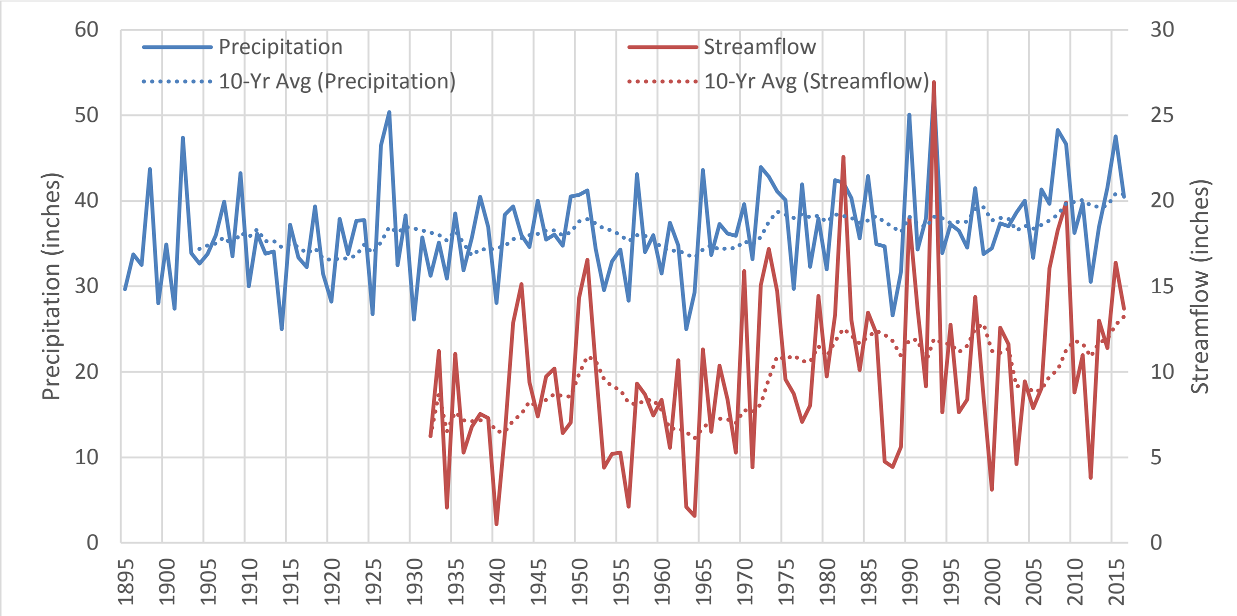


Figure 44. Annual precipitation (blue line) in Illinois Climate Division 5 and streamflow (red line) for the Vermilion River at Leonore. Dotted lines are 10-year moving averages.

It is tempting to conclude that the abrupt increases in precipitation and streamflow observed for both the Illinois and Vermilion Rivers after 1970 are due to climate change. However, historic data suggest a more complicated picture. Although there are few precipitation and hydrology records that predate 1870, Knapp (2005) examined the existing long-term precipitation records at Peoria, St. Louis, and Ottawa and found that the precipitation was often above average from 1840 to 1870. His results showed that the Upper Mississippi River watershed was relatively wet between 1840 and 1870 (Figure 45). As streamflow highly correlates to precipitation, it is reasonable to assume that the streamflow was likely also high during that period. Therefore, it appears that the increasing streamflow and precipitation after 1970 is part of long-term climatic and hydrologic variability. This demonstrates that it is important to use the entire available hydrological records, including wet, normal, and dry periods, for long-term water supply planning to characterize water availability under different conditions.

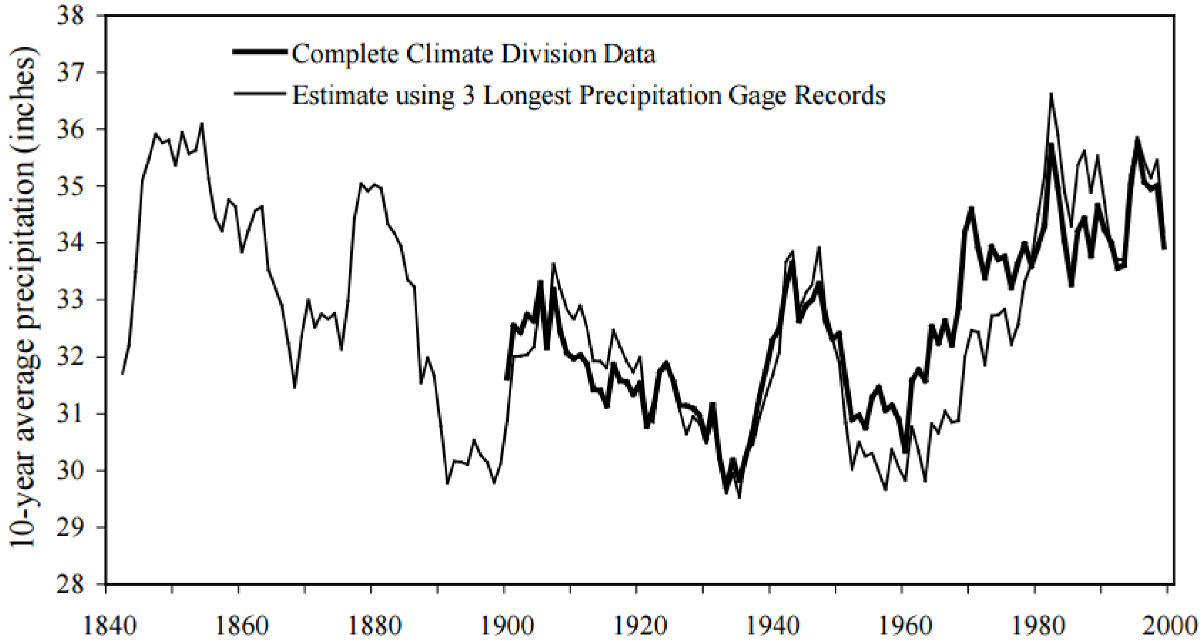


Figure 45. Estimated 10-year moving average precipitation for the Upper Mississippi River Basin, 1840-2000 (Knapp, 2005)

To analyze the differences between wet and dry periods in the region, three periods of record for the Vermilion River Leonore gage were examined: (1) the entire period of record, 1932 to 2016; (2) a period of extended low precipitation and streamflow, 1932 to 1966; and (3) a period of prolonged high precipitation and streamflow, 1970 to 2016. For all periods, the difference between the average precipitation and streamflow is defined as the estimated annual evapotranspiration, the amount of water returned to the atmosphere through evaporation and plant transpiration. Annual evapotranspiration rates are similar for the three periods, approximately 27 inches (Table 13). Given the error of estimation, it is reasonable to conclude that evapotranspiration has essentially been constant over the entire period. The average precipitation in the wet period is only 10 percent more than that of the dry period, and thus the average streamflow in the wet period is 50 percent greater than that of the dry period. These findings demonstrate that hydrologic variability is greater than climatic variability for the period of record, which makes water supply planning for drought conditions challenging.

Table 13. Comparison of Annual Average Precipitation, Streamflow, and Evapotranspiration for Three Selected Periods of Record for the Vermilion River Watershed (inches/year)

| Periods | Precipitation | Streamflow | Estimated Evapotranspiration |
|---|---|---|---|
| 1932-2016 | 37.1 | 9.9 | 27.2 |
| 1932-1964 | 35.0 | 7.7 | 27.3 |
| 1970-2016 | 38.5 | 11.6 | 26.9 |

### *4.3.3 Water Supply Drought in the Middle Illinois*

As discussed in the previous section, the climate in the Middle Illinois WSPR is variable, and the hydrologic variability is even higher. The natural phenomenon that has the largest impact on surface water supply is drought. Historic droughts often determine the yield that a water supply system (river or reservoir) can sustain.

Drought is the result of precipitation deficiency over a protracted period and is a temporary deviance from normal climatic conditions. It is different from aridity, which is a climate feature with a normal condition of low precipitation, such as in desert areas. In other words, drought is temporary and aridity is a permanent climate feature. Drought is often defined according to disciplinary perspectives. Commonly used definitions include three types of drought: meteorological, agricultural, and hydrologic (Wilhite and Glantz, 1985). Meteorological drought is based solely on the degree of dryness and the duration of the dry period, such as the amount of precipitation deficit over various time periods. Agricultural drought links the features of meteorological drought to agricultural impacts and focuses on precipitation shortages, soil moisture deficits, and unsatisfied irrigation needs. Hydrologic drought occurs when precipitation shortfalls over a prolonged period impact water supply systems, including streamflow, reservoir and lake storages, and groundwater, potentially causing substantive societal impacts. Hydrologic drought could be well beyond the borders of the meteorological drought area because different regions are interconnected by the natural hydrologic cycle and may be connected through man-made water supply systems. In this study, we focused on hydrologic drought to emphasize our focus on water supply and availability to human needs, as opposed to other hydrologic impacts, such as low streamflow needed for aquatic ecosystems. Hydrological droughts are referred to as water resources droughts to emphasize the impact on water supply.

Drought features are usually described by intensity, duration, frequency, and the relations among them. The severity of water resources droughts are classified by the ISWS as extreme, severe, and moderate. The extreme water resources drought has a similar impact to the most severe droughts on record. Typically over the past 120 years, most places in Illinois have experienced only three such droughts. The recurrence interval of extreme water resources droughts in Illinois is 25 to 50 years. Severe water resources droughts are such that vulnerable water supply systems will need to take some response, such as water-use restrictions, to address the impending drought threat. Often, restrictions will only occur with droughts more severe than a 10-year event. Moderate water resources droughts do not require any action on most vulnerable water supply systems.

In this study, only extreme water resources droughts are examined extensively, which have a recurrence interval of 25 to 50 years and a duration of 18 months or longer. The main features of an extreme water supply drought in Illinois are that it lasts two summers or longer, and that water supply systems are not able to recover during the intervening winter and spring. An extreme hydrologic drought is expected to occur once every 25 to 50 years on average, but it does not mean that it occurs once every 25 to 50 years. On the contrary, extreme hydrologic droughts in Illinois tend to occur within a relatively short period, such as those observed during the 1930s and 1950s, and may not happen again for the next 50 years.

The most extreme water supply droughts are often the longest lasting droughts, not necessarily the most intense droughts. The “drought of record” is the most extreme historical drought that occurred during the period of record when the appropriate hydrologic and climatic data were available. In fact, future droughts could be worse than the historical drought of record, as has occurred in Alabama, Georgia, and the Carolinas in 2007-2008 (Meyer et al., 2012).

Water supply droughts are the result of a meteorological drought, and are affected by water supply system properties and watershed or aquifer characteristics, or both. One meteorological drought may cause different levels of water supply droughts for different regions, depending on the local water supply systems and watershed/aquifer characteristics. Therefore, to fully evaluate water supply droughts and their impacts on community water supplies, both historical hydrologic data and local water supply systems need to be analyzed.

Drought is a natural hazard with social, economic, and environmental impacts. Based on Federal Emergency Management Agency (FEMA) estimates, annual losses from drought are $6-8 billion in the United States, an amount that is greater than any other weather-related natural disaster, including floods and hurricanes (Hayes et al., 2004). Human activities, such as water and land uses, can exacerbate the impacts of drought in a specific region.

Over the past 120 years, several extreme meteorological droughts have occurred in Illinois. The most extreme ones include the 1930s Dust Bowl drought and the 1950s drought, which covered large areas beyond Illinois. The most commonly used drought index, the Palmer Drought Severity Index (PDSI), is used to quantify the severity of meteorological droughts. PDSI uses precipitation deficits and temperatures to identify periods of meteorological drought. Negative PDSI values mean dry conditions, and extreme, severe, and moderate droughts have PDSI values of -4 or less, -4 to -3, and -3 to -2, respectively. Figure 46 shows the statewide PDSI values since 1895. Extreme meteorological droughts include the years 1902, 1915, 1931, 1934, 1936, 1940, 1954, 1964, 1988, and 2012. The most extreme meteorological drought occurred during the summer of 1934, and the second most extreme meteorological drought was in 1931. The frequency and severity of droughts in Illinois after 1965 are much less than before 1965 (State Water Planning Task Force, 2011). The drought in 2005 is only classified as severe, yet it caused agricultural losses of $1-2 billion in Illinois (Kunkel et al., 2006). The drought in 2012, the most recent drought in the region, caused crop losses of about $3 billion in Illinois (Knapp, 2017, Natural Resource Defense Council, 2013). Notably, the classifications of water resources droughts and meteorological droughts are different because they characterize different types of droughts.

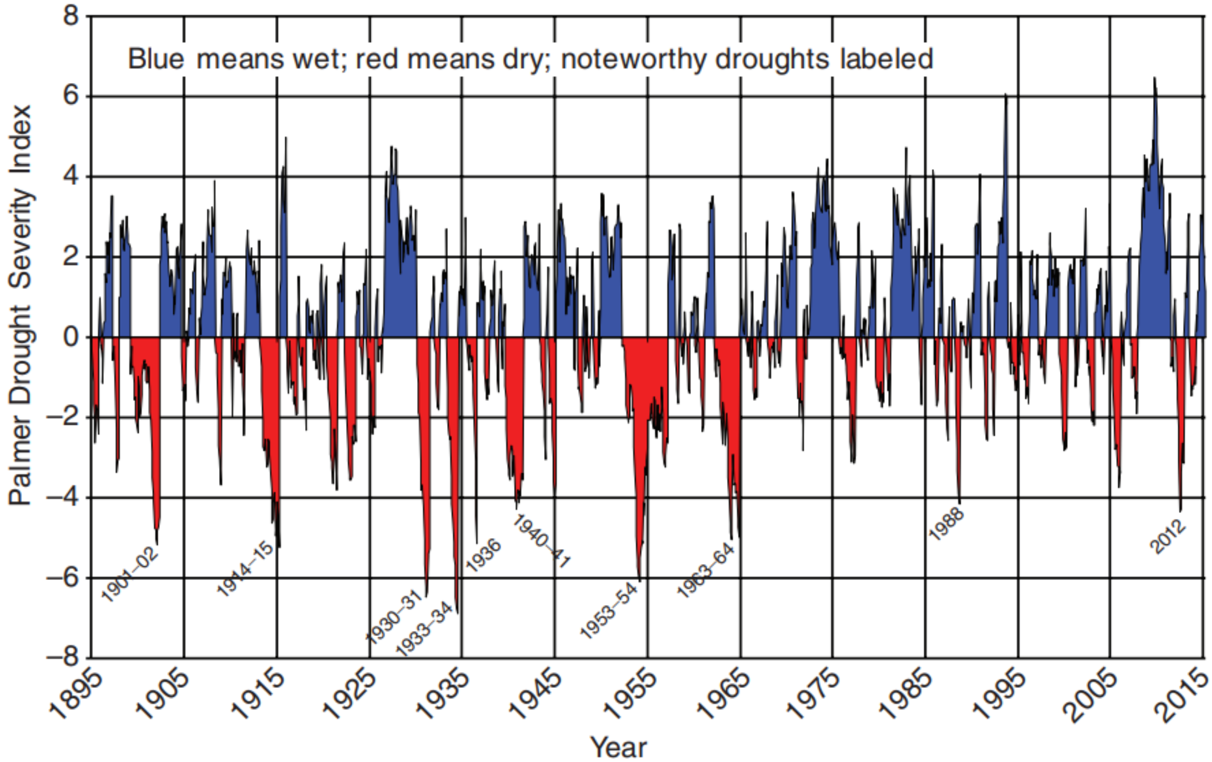


Figure 46. Monthly Palmer Drought Severity Index (PDSI) for Illinois, 1895-2015 (State Climatologist Office for Illinois; Knapp et al. [2017])

Meteorological drought in the Middle Illinois WSPR generally has the same temporal pattern as a statewide meteorological drought. Figure 47 shows the PDSI of the past 120 years for Illinois Climate Division 4, which covers most of the region's counties. Extreme droughts in the Middle Illinois Region include 1902, 1915, 1931, 1934, 1936, 1940, 1964, 1988, 2005, and 2012. Again, the most extreme drought occurred during the summer of 1934, and the second most extreme drought was in 1931.

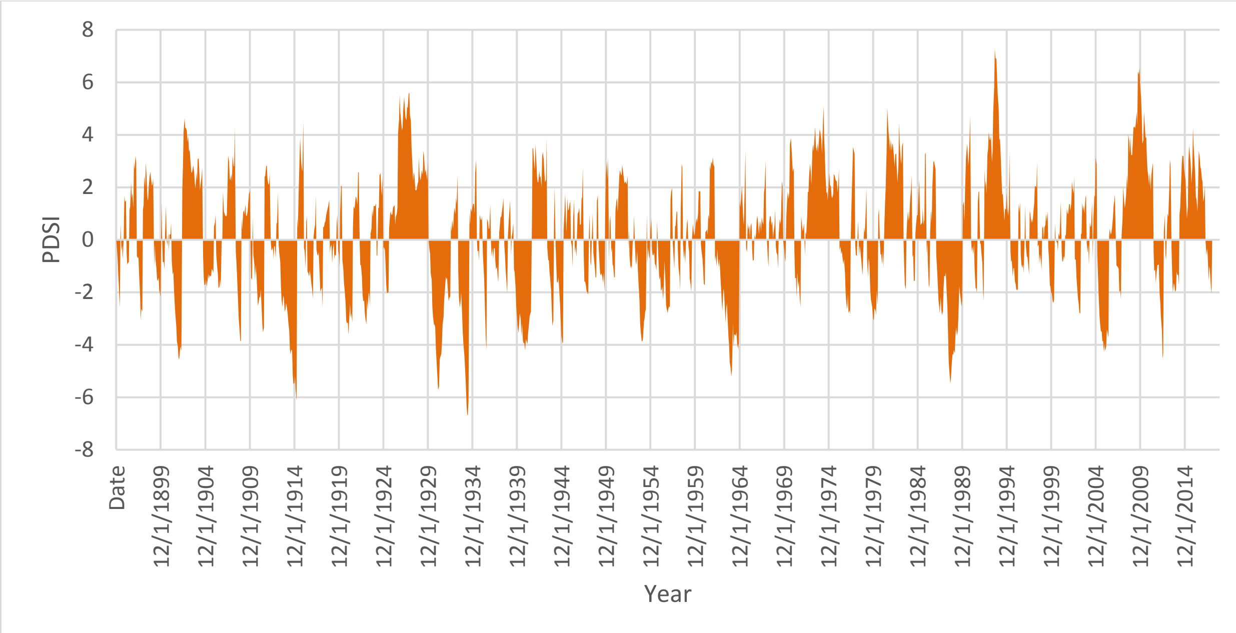

Figure 47. Monthly Palmer Drought Severity Index (PDSI) for Illinois Climate Division 4

## 4.4 Effluent Discharges

Water withdrawn from surface or groundwater sources is used for a variety of purposes to meet human needs. Part of the water withdrawal is consumed and is defined as a consumptive use of water. The part that is not consumed could be reused with or without treatment or returned to the environment as effluent discharge (Knapp, 1992). The effluent from large wastewater treatment plants may be reused for industrial purposes through a direct diversion from the treatment plant. If the wastewater from large treatment plants is released directly to a stream, the available streamflow (a mixture of treated wastewater and natural flow) downstream of the release is increased. During drought periods, most of the tributaries in Middle Illinois would have no flow except for treated wastewater discharges. In many of these cases, the effluent is gradually absorbed into the streambed as the effluent flows downstream. The effect of the effluent may be local and temporary. Effluent originating from surface water sources would offset a portion of the reduction of flow on account of the surface water withdrawal when the effluent is returned to the same source from which it was taken. Effluent originating from groundwater sources would be added to the surface water system. However, groundwater withdrawals may have long-term impacts by reducing baseflow contributions to streamflow.

For the period of 2010-2014, there were 115 effluent points of 0.1 cfs (0.06 Mgd) or greater discharged to streams within the Middle Illinois Region, with an annual average effluent discharge of 612 cfs (395 Mgd) (Figure 48). Among the 115 effluents, only 7 dischargers released effluent of at least 10 cfs (6.5 Mgd), all of which discharged to the Illinois River. The largest effluent dischargers were power plants along the Illinois River, which discharged 397 cfs (257 Mgd) of effluent. Power plants also withdraw their water from the Illinois River, making the consumptive use or net impact on streamflow from power plant water use relatively small with respect to the available streamflow.

Table 14 shows the municipal effluent discharges of at least 1 cfs (0.65 Mgd) within the Middle Illinois Region. The total effluent discharged from these 20 municipal dischargers was 76.9 cfs (49.7 Mgd) for 2010-2014. Twelve municipal effluents accounted for 59.3 cfs (38.3

Mgd) of the wastewater discharged to the Illinois River, accounting for 77 percent of the total municipal effluent. Eight municipalities discharged their wastewater to tributaries in the region. Although the effluent amount discharged to tributaries is only 17.6 cfs (11.4 Mgd), their impact on low flows is higher because many small streams have low flows during drought conditions.

Effluent amounts from industrial users or community wastewater treatment plants is related to water withdrawal and water use efficiency. Combined sanitary sewer systems collect not only wastewater from domestic, commercial, or industrial users, but also flow from stormwater drains. Therefore, the highest effluent discharge from wastewater treatment plants often occurs in the spring when it is wet. Effluent from wastewater treatment plants in the spring could be 50 percent greater than the annual average, and the lowest monthly effluent amounts are about 70 percent of the annual average effluent. The natural streamflow during low flow conditions could be less than 10 percent of the average flow, however, and thus the relative impact of effluent on surface water is much higher during low flow conditions (Knapp, 1990).

Table 14. Large Municipal Effluent Discharges in the Middle Illinois Region

| **System** | **Receiving River** | **Average Effluent** | |
|---|---|---|---|
| | | (cfs) | (Mgd) |
| Greater Peoria | Illinois River | 29.4 | 19.0 |
| East Peoria | Illinois River | 5.5 | 3.6 |
| Ottawa | Fox & Illinois River | 4.5 | 2.9 |
| Pontiac | Vermilion River | 3.9 | 2.5 |
| Marseilles WWTP | Illinois River | 3.7 | 2.4 |
| Pekin | Illinois River | 3.6 | 2.3 |
| Streator | Vermilion River | 3.4 | 2.2 |
| Morris | Illinois River & Nettle Creek | 2.7 | 1.7 |
| Mendota | Mendota Creek | 2.5 | 1.6 |
| Washington | Farm Creek | 2.0 | 1.3 |
| Princeton | Skin-Epperson-Big Bureau | 2.0 | 1.3 |
| Peoria CSOS | Illinois River and Peoria Lake | 1.9 | 1.2 |
| Peru | Illinois River | 1.8 | 1.2 |
| Creve Coeur | Illinois River | 1.6 | 1.0 |
| LaSalle | Illinois River | 1.5 | 1.0 |
| Peru[1] | Illinois River | 1.5 | 1.0 |
| Spring Valley | Illinois River | 1.5 | 1.0 |
| Fairbury | Indian Creek-Vermilion River | 1.5 | 1.0 |
| Oglesby STP | Vermilion River | 1.1 | 0.7 |
| Coal City | Claypool ditch | 1.1 | 0.7 |

[1]Peru has two separate NPDES wastewater discharge permits.

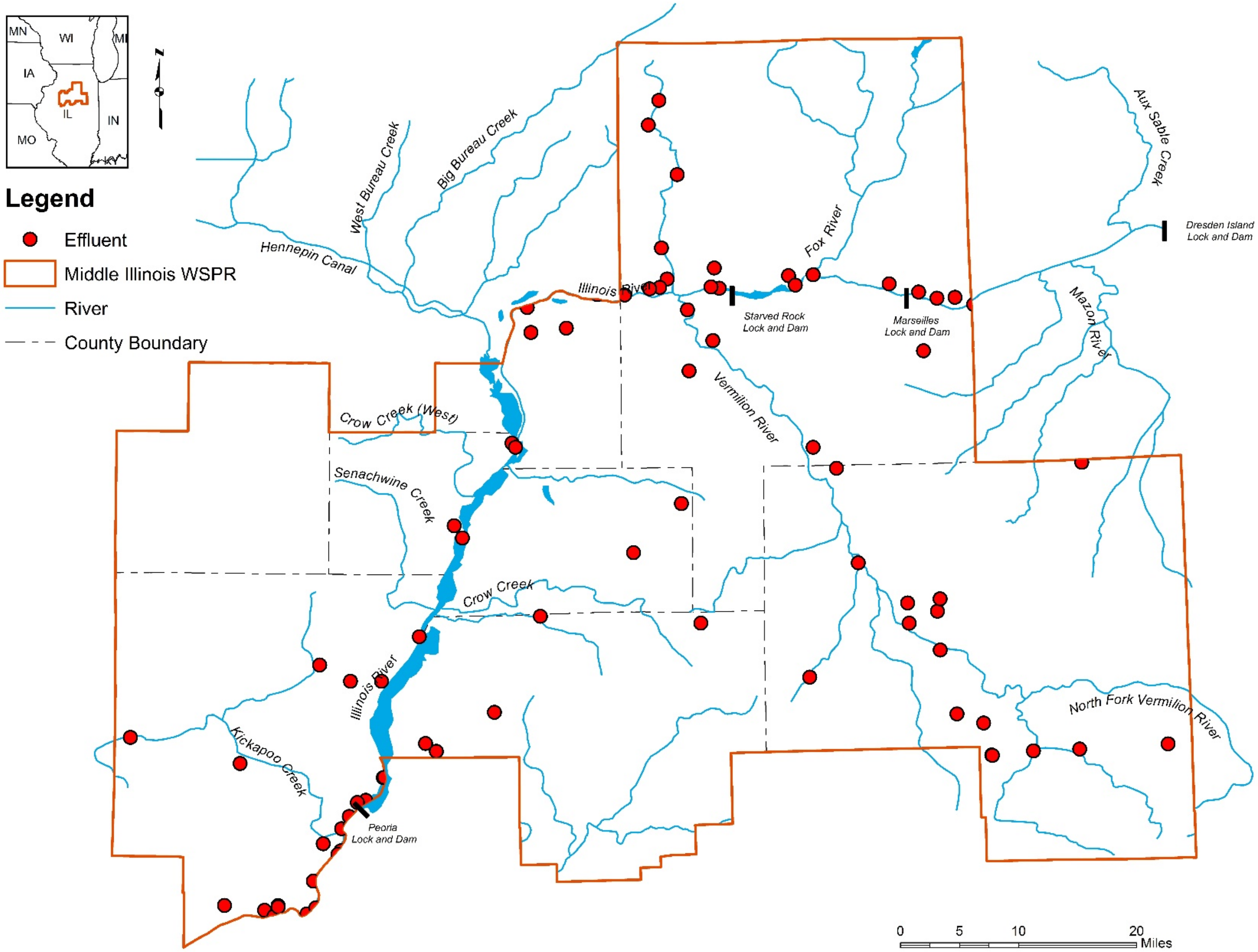


Figure 48. Effluent discharges in the Middle Illinois Region for the period 2010-2014

## 4.5 Water Diversions

### *4.5.1 Lake Michigan Diversion*

Although the Middle Illinois WSPR does not use water diverted directly from Lake Michigan, the diverted Lake Michigan water constitutes a significant component of streamflow in the Illinois River, especially in low flow seasons or during extreme drought conditions. Furthermore, public water supplies in Chicago and surrounding areas have a greater impact on the amount and timing of the Lake Michigan diversion than meteorological or hydrological factors. As a result, public water use in the Chicago region is the primary factor affecting water supply droughts in the Middle Illinois Region other than the local meteorological and hydrological characteristics. Therefore, it is vital to understand the dynamics and features of the Lake Michigan diversion.

The Lake Michigan diversion system is shown in Figure 49. The Chicago Sanitary and Ship Canal was constructed to connect the Chicago and Des Plaines Rivers in 1900, allowing the flow direction of the Chicago River to be reversed westward to the Illinois River instead of to Lake Michigan with the aim to keep wastewater and flood water out of Lake Michigan. The North Shore and Calumet Sag Channels were completed in 1910 and 1922, respectively, increasing the diversion rate to 8,500 cfs briefly during the 1920s.

In 1930, the U.S. Supreme Court ordered the diversion to be reduced to 1,500 cfs by 1939, excluding Chicago's growing public water supply from Lake Michigan. Changes to the Lake Michigan diversion were so remarkable that the hydrologic regime in the Illinois River before 1939 would not represent that after 1939. Thus, when choosing the representative hydrologic period of record in the hydrologic analysis for the Illinois River, streamflow records before 1939 were not used.

In 1967, the U.S. Supreme Court set a new limit of the diversion at 3,200 cfs, including the public water supply from Lake Michigan. The diverted water is divided into three categories: (1) direct diversion that consists of lockage, leakage, navigation, and discretionary diversion for sanitation; (2) surface runoff from the 673 square mile watershed that drained to the lake prior to the reversal of the Chicago River flow; and (3) public water supply to meet the needs of Chicago and surrounding areas.

The Lake Michigan diversion has been reduced substantively since 1994 because of many factors such as improved water-use efficiency, reduced leakage, low precipitation, and low lake levels. In addition, the discretionary diversion for sanitary purposes was reduced from 270 to 100 cfs starting in water year 2015. The discretionary diversion from Lake Michigan during the cool season (October through March) has ceased and it could be discontinued during the warm season. It is believed that this change of operation will decrease flow in the Illinois River during droughts; thus the hydrologic analysis for the Illinois River uses only the period of record between 1940 and 1993. For details of the history of the Lake Michigan diversion and its impact on water supply, see Meyer et al. (2012).

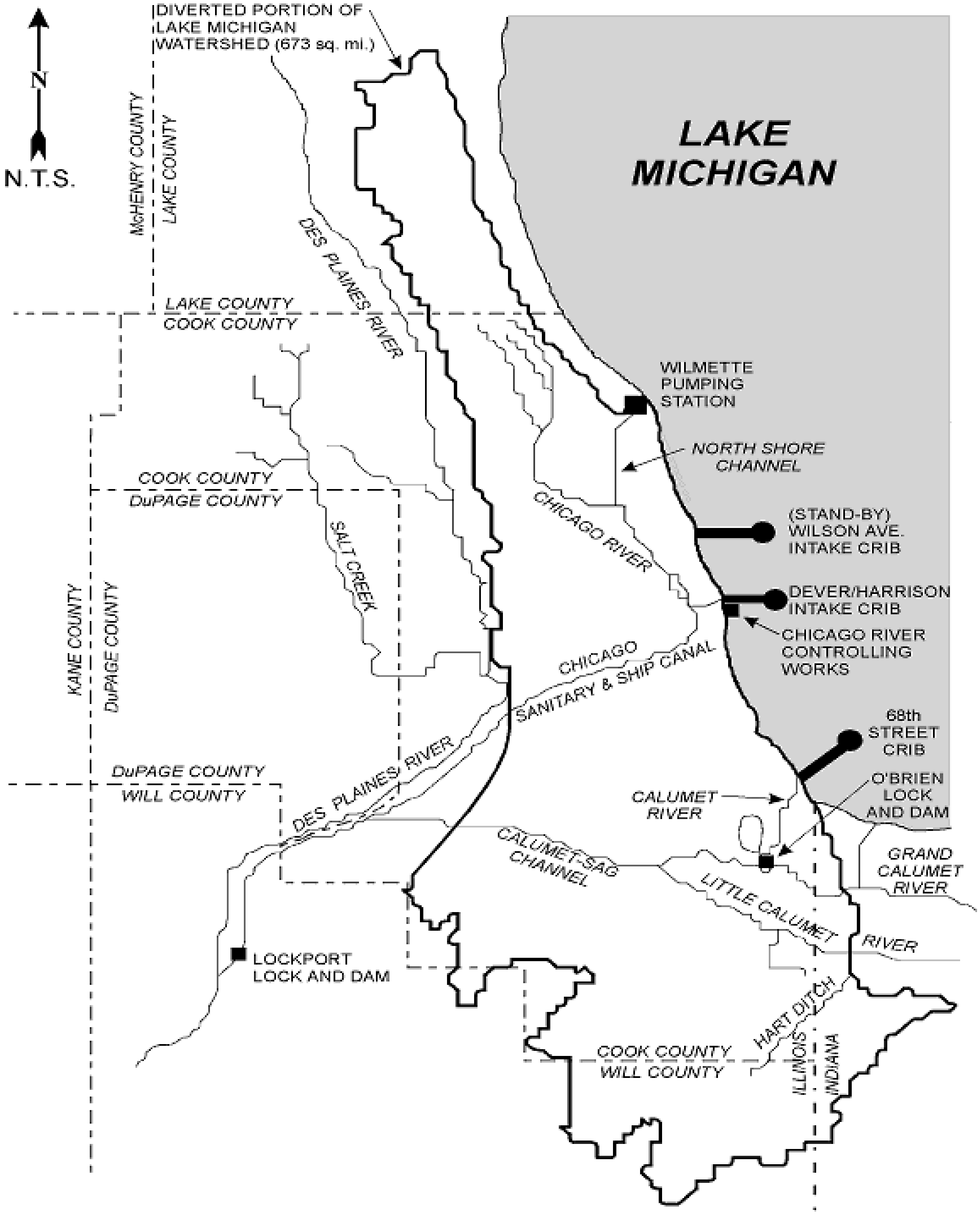


Figure 49. Lake Michigan diversion system at Chicago, adopted from (Meyer et al., 2012)

### *4.5.2 Hennepin Canal Diversion*

The Hennepin Canal, formerly known as the Illinois and Mississippi Canal and also known as Hennepin Canal Parkway State Park, is an abandoned canal in northwest Illinois, connecting the Mississippi River at Rock Island and the Illinois River near Hennepin (Knapp and Russell, 2004). The canal runs 75.2 miles from the Rock River near Moline eastward to the Illinois River. A 29.3 mile-long feeder canal running south from the Sinnissippi Dam on the Rock River in Rock Falls, IL supplies fresh water to the system. The canal was completed in 1907 but abandoned in 1951 because of railroad competition. It was resurrected with diverted water from the Rock River to the canal in the late twentieth century as a recreational waterway.

## 4.6 Low Flow Fluctuations in the Upper Illinois Waterway

During low flow and drought conditions, Illinois River flow is controlled by eight locks and dams along the Illinois Waterway. Each dam's outflow facilities are managed to maintain target pool levels (and sufficient channel depth). This management can noticeably impact the sub-daily flow conditions on the Illinois River, but its impact on long-term water supply is generally minimal.

Recent reductions in low flow quantities have exposed an aspect of low flow characteristics in the Illinois Waterway: high-frequency flow fluctuations associated with lock operations. These fluctuations were especially notable during the 2012 drought as they pertained to IDNR's management of water withdrawal permits and protected minimum flow on the Illinois River (Figure 50). Flows in the upper Illinois River can rapidly rise and fall in response to lock operations. The ISWS conducted two aspects of analyses to better characterize and understand these flow fluctuations. The first was a hydrologic analysis of available flow and stage records (from the USGS and U.S. Army Corps of Engineers [USACE]) in the portion of the waterway from the Starved Rock Lock and Dam upstream to the Lockport powerhouse to identify the impact of lock operations on low flow fluctuations. The second one was a hydraulic modeling analysis of the lock operations and low flows in the same reach of the waterway to explore alternative operations. The hydraulic modeling effort was eventually reduced to the specific reach between Starved Rock and Dresden Island to avoid the effects associated with inconsistencies in the hydrologic inputs to the model.

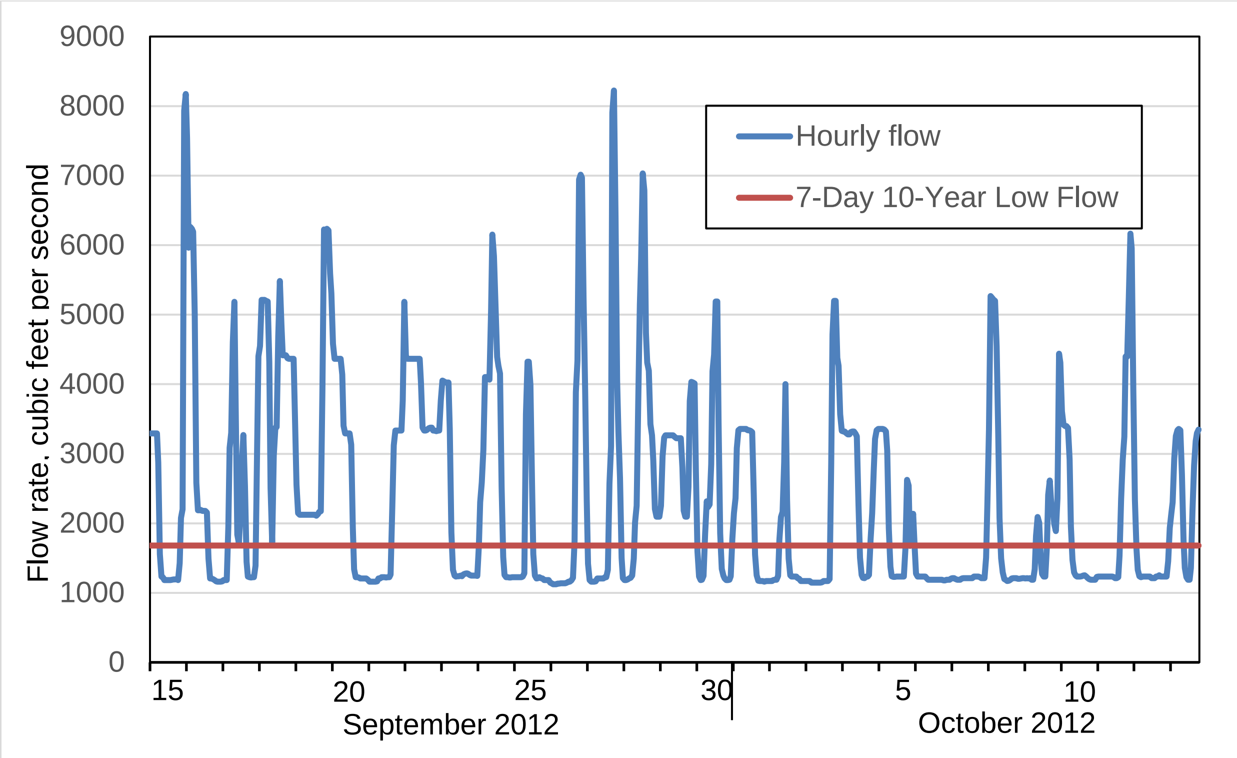


Figure 50. Hourly flows on the Illinois River at Marseilles, IL, Sept 15-Oct 14, 2012

### *4.6.1 Illinois Waterway Locks and Dams*

The Illinois Waterway system meanders from the mouth of the Calumet River to the mouth of the Illinois River at Grafton, Illinois. It consists of 336 miles of river, lakes, and canals, and connects the Great Lakes to the Gulf of Mexico via the Mississippi River. In 1900, the CSSC replaced the older and narrower Illinois and Michigan Canal that was completed in 1849. Completion of the CSSC also reversed the flow of the Chicago River and drained it to the Illinois River instead of Lake Michigan.

A navigation channel depth of 9 feet along the Illinois Waterway is maintained by the USACE. The locks and dams are listed in Table 15. The slope of the Illinois Waterway is very gentle for the first 231 miles from the mouth of the Illinois River. Most of the lift occurs in the last 100 miles of the Waterway. Figure 51 demonstrates the profile of the Illinois Waterway dropping from 578.5 feet above sea level at Lake Michigan to 419 feet at the Mississippi River at Grafton, Illinois.

Table 15. Pertinent Information for Locks and Dams along the Illinois Waterway

| Lock & Dam Name | Location | River Miles Above Mississippi | Pool Level (ft) |
|---|---|---|---|
| T.J. O'Brien L&D | Chicago | 326 | 578.5 |
| Lockport L&D | Lockport | 291 | 577 |
| Brandon Road L&D | Joliet | 286 | 539 |
| Dresden Island L&D | Morris | 271 | 505 |
| Marseilles L&D | Marseilles | 245 | 483 |
| Starved Rock L&D | North Utica | 231 | 458 |
| Peoria L&D | Peoria | 157 | 440 |
| La Grange L&D | Beardstown | 80 | 430 |

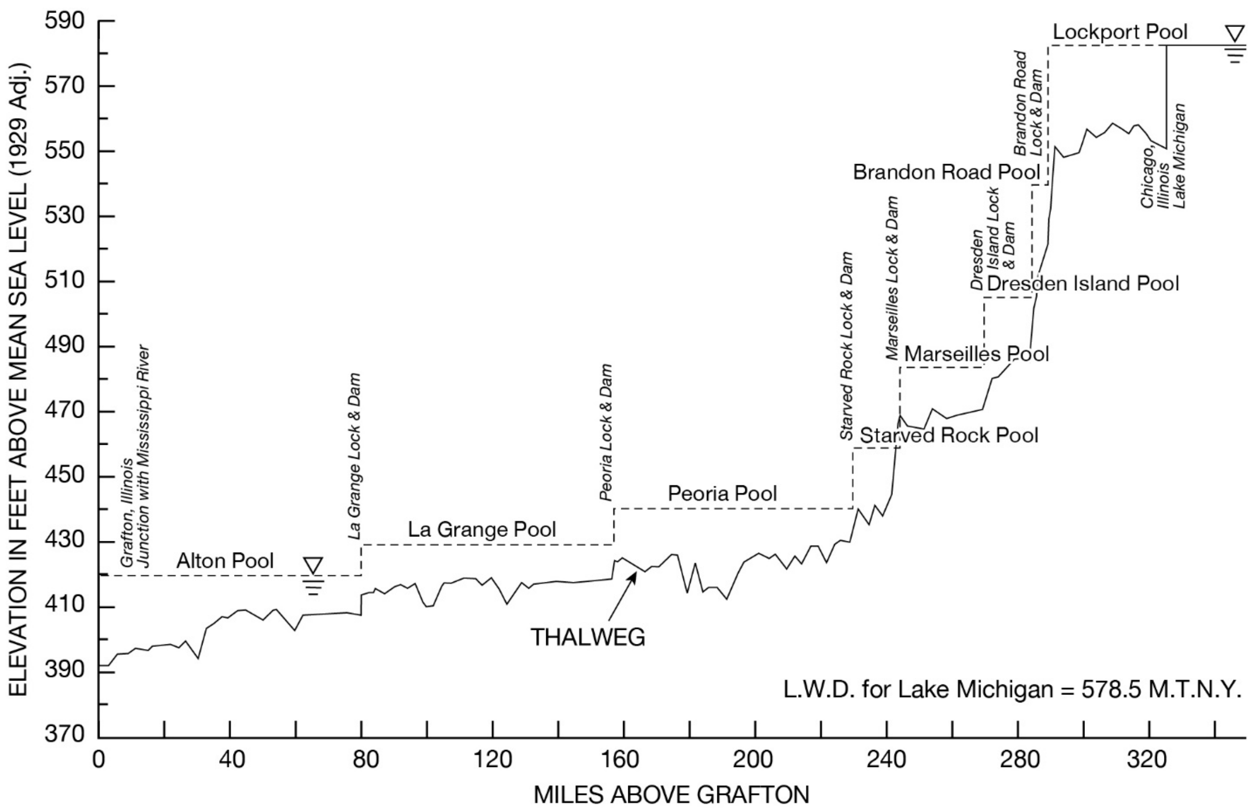


Figure 51. The profile of the Illinois Waterway, adopted from Demissie and Bhowmik (1986)

### 4.6.2 Impact of Current Lock Operations

The hydrologic analysis of gage records identified many inconsistencies when compared to the available calculated flow amounts. These inconsistencies are a result of normal variability and measurement error in flow records of natural streams and are typically associated with the frequency of measurements and shifting of the stage-discharge relationship that occurs between measurements. Low flow observations for the Illinois River at Marseilles, for example, can be influenced by pool fluctuations that are controlled by the operation of the Starved Rock Dam located 16 miles downstream. Analyses of such factors help identify which gage(s) and flow records may be the most consistent for making near real-time decisions concerning permitted water withdrawals.

The streamflow records at selected USGS gages and the records of release, leakage, and lockage from the locks and dams were obtained from the National Water Information System (NWIS) and the USACE, respectively. The records were selected for the periods of June through December of 2005 and 2012 to cover drought conditions. These data were used for hydrologic analysis, hydraulic model calibration, and alternative development. The results of the analyses were similar for 2005 and 2012. Thus, only the results for 2012 are described below.

The operations of Dresden Island and Marseilles Locks and Dams were compared to identify the difference of low flows, as the distance between Dresden Island L&D and Marseilles L&D is approximately 25 miles and there are no major tributaries in between. The variability and fluctuation of the flow at Marseilles L&D is greater than that of Dresden Island in that the coefficient of variation (i.e., the ratio of the standard deviation to the mean) for Dresden Island was 65 percent, and the coefficient of variation for Marseilles L&D was 109 percent. It appears that the Dresden Island outflow is noticeably higher than the Marseilles outflow during low flow conditions. However, the reported flow from the Marseilles L&D is gate outflow alone and does not include the roughly 1000 cfs that consistently leaks through the dam. When this leakage is added to the gate outflow, the total flow from the Marseilles L&D is comparable to, and at times greater than, the Dresden Island low flow.

To take a closer look at the operation of Marseilles L&D, the bi-hourly flow data are shown in Figure 52. Gate releases from the Marseilles Dam during low flow conditions tend to be step functions, which are multiples of 650 cfs. To examine how fast the gate flow is reduced to 0 cfs, the frequency of the flow decreases in 2012 with respect to the magnitude within one-time step (two hours) was analyzed and shown in Figure 53. When the flow was reduced to 0 cfs, it was reduced from 650 to 0 cfs for 38 percent of the time. However, in 62 percent of the time, flow was reduced by 1300 cfs or more. When flow was reduced to 650 or 1300 cfs, the frequency of the flow decreased in 2012 with respect to the magnitude within the one-time step, which is shown in Figure 54. During 52 percent of the time, flow was reduced by only 650 cfs, but in 48 percent of the time, flow was reduced by 1300 cfs or more. The rapid decrease of streamflow by 1300 cfs or more can lead to more rapid responses in correcting stage levels; however, during low flow conditions, this decrease in flow is not considered to be optimal as it may potentially cause adverse impacts on aquatic ecosystems.

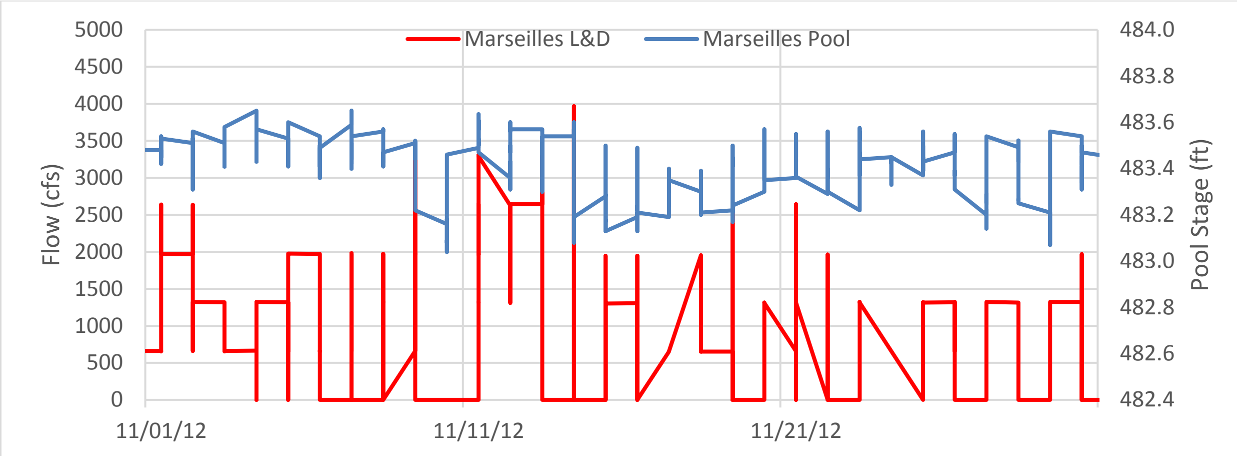


Figure 52. Bi-hourly flow and pool level at Marseilles L&D in November 2012

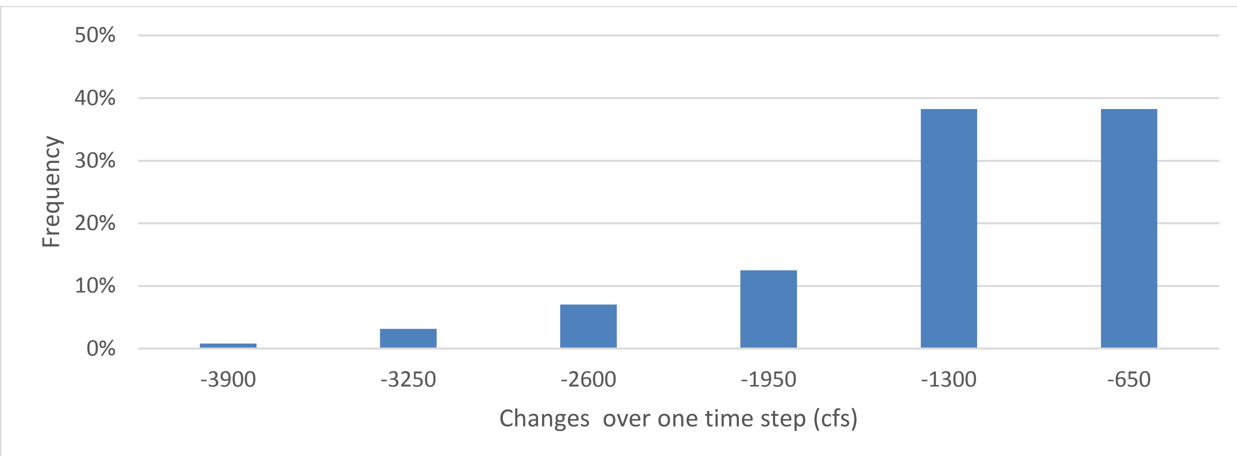


Figure 53. The frequency of flow decreased when flow at Marseilles was reduced to 0 cfs in 2012

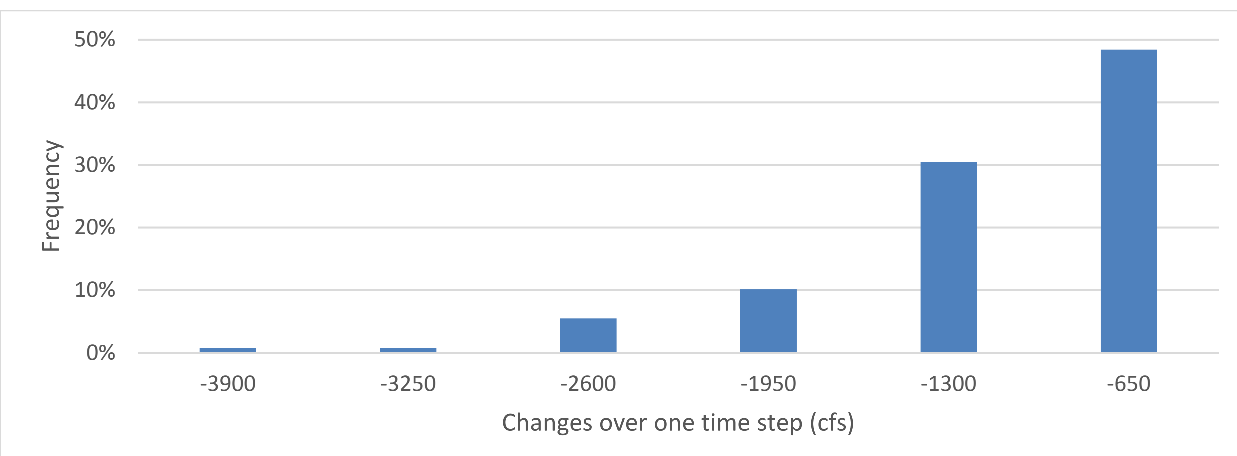


Figure 54. The frequency of flow decreased when flow at Marseilles was reduced to 650 or 1300 cfs in 2012

The comparison between operation of Dresden Island and Marseilles L&D and the frequency of flow decreases provides insights for developing alternatives that may reduce the variation of the flow release at Marseilles while maintaining the navigational channel above the dam. The alternatives are evaluated using hydraulic modeling, considering viability and reliability.

### *4.6.3 Hydraulic Simulations of Alternative Lock Operations*

UNET is a one-dimensional unsteady flow model that simulates flow in a complex network of open channels. The UNET unsteady flow routing model was used to simulate flow and stage conditions in the upper Illinois River, focusing on the Marseilles pool during the low flow conditions that existed in September and October of 2012. The model was used not only to replicate the effects of the observed gate operations and flows from the dams on the river, but also to investigate alternative operation schemes. Operation of the powerhouse and dam at Lockport (by the Metropolitan Water Reclamation District) often creates alternating periods of high discharge when the turbines are producing power and low discharge when water is being retained for the next wave of power production. At each successive downstream dam, the USACE considers the operational changes being made at the dam located immediately upstream and anticipates the associated rise and fall of flow amounts. The UNET simulations indicate that the USACE is effectively able to pass these flow fluctuations farther downstream and still maintain the operational levels of pools behind each lock and dam. However, with these operations there is relatively little reduction in flow fluctuations downstream.

The operation alternatives simulated in this study suggest that modifications can be made in the pool management at each dam to incrementally lessen the amount of flow fluctuation downstream and thereby increase the short-term minimum flow levels. Simulated flow releases associated with selected operation scenarios are shown in Figure 55 and Figure 56 for the Dresden Island and Marseilles Dams, respectively. Various operating options or scenarios were simulated, but the scenarios shown in Figure 55 and 56 involve:

(1) “Shrinking” the range of the operational pool at each lock and dam during low flow conditions; specifically, trying to keep the pool stages in the upper half of the normal operating range during low flow conditions. For the Marseilles Dam, if the normal operating range is 483.2 to 483.6 feet, the gate operation would attempt to keep the low flow pool stage between 483.4 and 483.6 feet.

(2) Changing gate openings incrementally (usually by 650 cfs) to avoid large changes in discharge and rapid changes in stage.

(3) Establishing a minimum target release amount, such that lower flow releases would occur infrequently, during the worst low flow periods when low flow stages would otherwise fall below the normal operating range (483.2 feet for Marseilles Dam). By adopting the first two operating principles listed here for the Dresden Island and Marseilles Dams, the simulated output in Figures 55 and 56 indicates that minimum outflows of 1300 cfs and 1500 cfs could have been adopted at Dresden and Marseilles, respectively, without causing either pool to fall below its normal operating range. Of the 1500 cfs shown in Figure 56, 1000 cfs is attributed to dam seepage and 500 cfs to gate outflow.

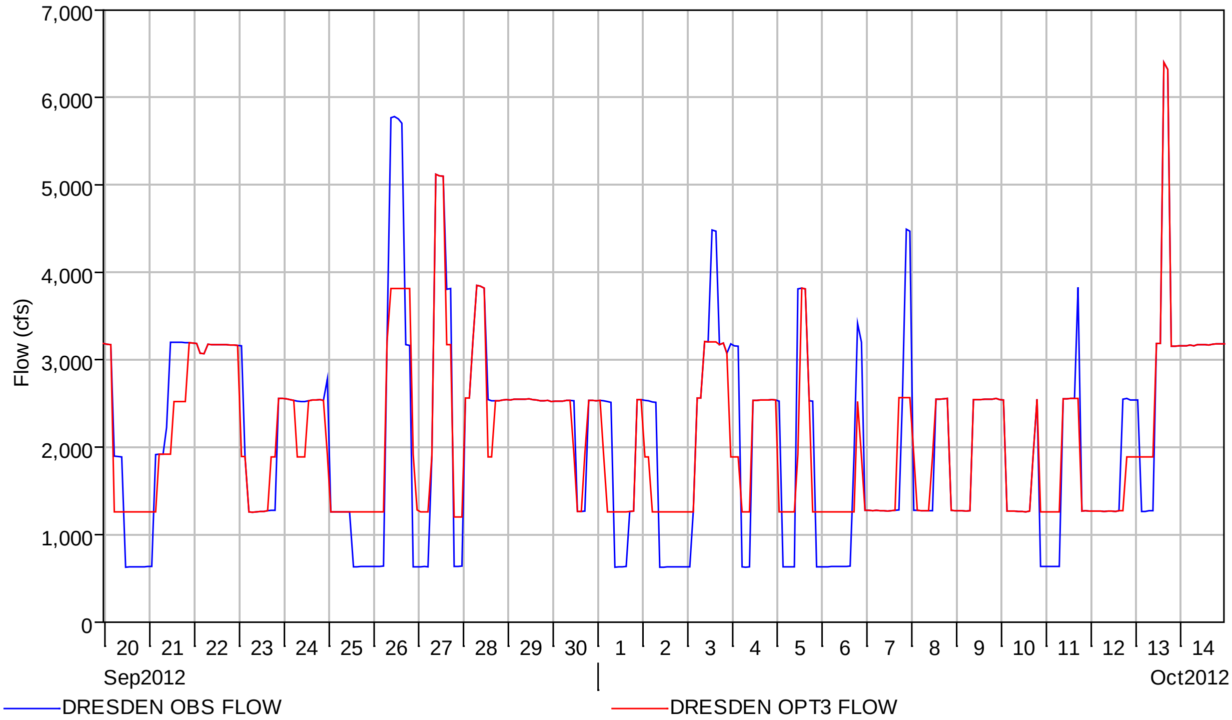


Figure 55. Comparison of observed Dresden Island Dam outflow (blue) in September-October 2012 to a simulated operation alternative (red), showing an associated increase in the minimum release

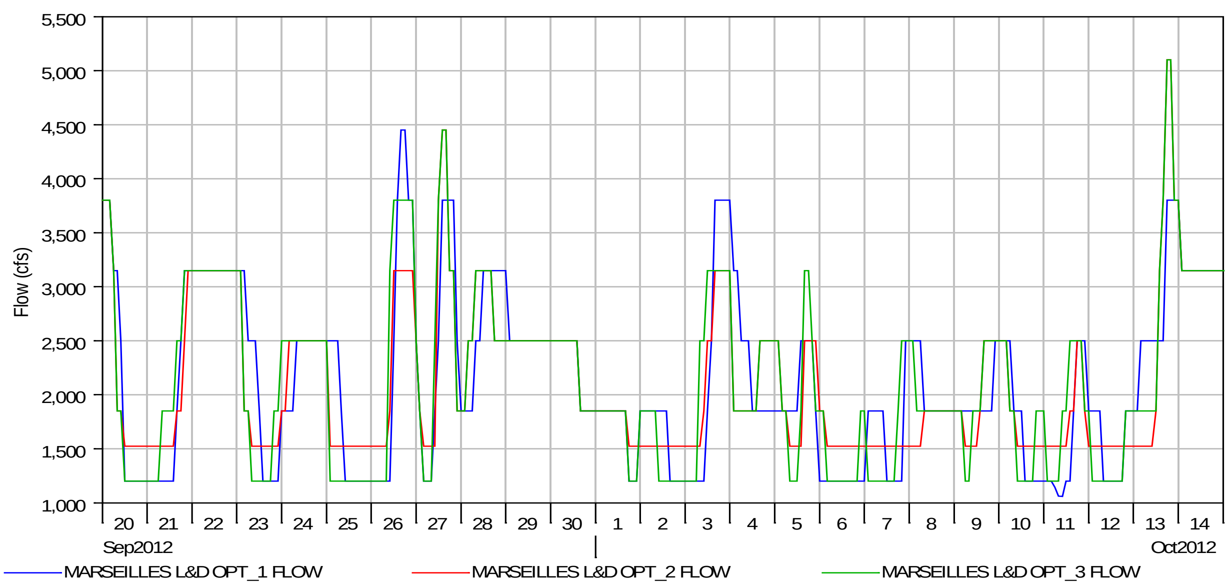


Figure 56. Comparison of Marseilles Dam outflow for selected operation alternatives (September-October 2012)

## 4.7 Public Water Systems

Three public water systems (Peoria, Pontiac, and Streator) in the Middle Illinois Region obtain all or part of their water from surface water sources. All three systems are owned and operated by the Illinois American Water Company (IAWC). Peoria uses both groundwater and surface water sources, with about 60 percent of the public water supply originating from groundwater. Because of these sources and the large flows in the Illinois River, there appears to be plenty of water for Peoria. The Pontiac and Streator public water systems, however, are facing water quantity and quality challenges, and are evaluated in more detail below.

### *4.7.1 Yield Analysis*

To assess surface public water vulnerabilities and address the question of "how much water use is too much" (Zhang and Balay, 2014), yield analyses are conducted to estimate the maximum amount of water withdrawals that would be necessary during a critical drought duration without running out of water (Knapp et al., 2017). To estimate yields, data on streamflow, reservoir capacity, precipitation, and evaporation are needed. The ISWS yield analysis calculates two different yields to reflect the uncertainty in the data: 50 percent confidence yield (Y50) and 90 percent confidence yield (Y90). Y50 is the yield that is expected to be closest to the "true" yield and the chance of overestimating (or underestimating) is 50 percent. Y90 is the yield that has a 90 percent chance of underestimation. That is, we are 90 percent confident that the "true" yield is greater than or equal to Y90.

For a specific public water supply system, the water demand is compared with the estimated yields (Y50 and Y90) to identify water supply risks. Figure 57 graphically shows how a system is classified based on water supply risks. If a system demand is greater than Y50, the system is classified by ISWS as an inadequate system. If a system demand is greater than Y90 but less than Y50, it is an at-risk system. If a system demand is less than Y90, the system is classified as an adequate system.

For both the Pontiac and Streator systems, low river flows during the historical droughts of 1953 and 1988 have provided the greatest threat to the adequacy of the system. Neither system experienced a supply shortage during those droughts, but the two droughts provide the benchmark for determining the available yield for the two systems.

Three types of information were used to evaluate the adequacy of supply for the Pontiac and Streator systems:

(1) ISWS file records on the system performance of the two systems are available for the two worst low flow periods on the Vermilion River over the past century, specifically the 1953 and 1988 droughts. As both systems have experienced changes in water use and water supply storage, the system performances during these past droughts need to be extrapolated to reflect the present management practices and system configuration at Pontiac and Streator.

(2) USGS flow records on the Vermilion River located downstream of the Pontiac and Streator withdrawals, with one record dating back to 1914, are used to evaluate the relative frequency of low flow events and identify the worst low flow periods of the historical record.

(3) Water budget models of the Pontiac and Streator systems, developed at the ISWS, are used to juxtapose the climate and streamflow data of past drought periods with the present water supply storage conditions. These models provide a daily accounting of

storage of the in-channel and off-channel storages using hydrologic and climatic inputs (river inflow, precipitation, and evaporation), water use withdrawals, and management practices such as water transfers between the river and off-channel storage. Such modeling provides an evaluation of the potential yield of the current system if conditions similar to the worst droughts on record were to recur. For Pontiac, Hecht (2011) adapted a version of the water budget model to include the impacts of source blending and nitrate water quality management on off-channel storage.

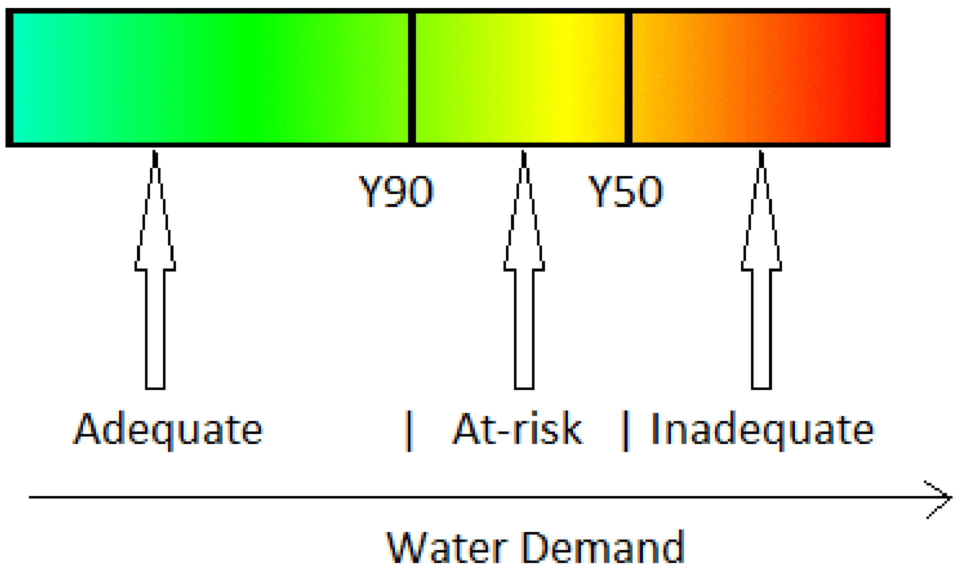


Figure 57. Schematic of comparison between water demand and yield to identify water supply risks

### *4.7.2 Pontiac Public Water System*

The Pontiac public water system is owned and operated by the Illinois American Water Company (formerly Northern Illinois Water Corporation), serving Pontiac, a small city with about 12,000 residents (Hecht, 2011, Hecht et al., 2013). Pontiac is in the agricultural Vermilion River watershed and withdrew its drinking water directly from the river until 1993. Since then, the system withdraws water from a low-head dam, named the Mill Street Dam, which raises the stage of the river to form a pool with a maximum water depth of about 8 feet and a width of 140 feet (Evans et al., 1979). Under a normal pool stage, the storage capacity of the pool is 153 acre feet, and 70 percent of the storage (107 acre feet) is above the top of the intake that is 1000 feet above the dam. The drainage of the Vermilion River upstream of the dam is estimated to be 580 square miles. The Vermilion River at Pontiac had been dry for over four months in 1988 and for periods in 1989, 1991, and 2005. This exposed the water supply risk that Pontiac faced.

The city converted an abandoned quarry into an off-channel reservoir system after the drought in 1988-1989 and the declaration of federal environmental regulations in 1992 limiting $NO_3$-N concentrations in drinking water to 10 mg/L. The quarry has a capacity of 985 acre feet and a surface area of 115 acres (reservoir #1, 2, 3, and 4), estimated from the results of IDNR’s bathymetric survey in 2011. Reservoir #5 has an additional storage capacity of 394.2 acre feet. The off-channel reservoir system stores water pumped from the Vermilion River to provide water supply when the river streamflow is insufficient or to blend with river water to lower the nitrate concentration when the Vermilion River water contains nitrate concentrations above drinking water standards.

Water in the low-head impoundment can be pumped to the off-channel reservoir or directly to the treatment plant. There are a series of pumps to convey water through the treatment system: (1) four pumps (total capacity 4.6 Mgd [7.1 cfs]) convey water from the river to the treatment plant; (2) one pump (capacity 4.5 Mgd [7.0 cfs]) conveys water from the river to the off-channel reservoir; and (3) three pumps (total capacity 5 Mgd [7.8 cfs]) divert water from the off-channel reservoir to the treatment plant.

Figure 58 shows the schematics of the Pontiac public water system. The system's operation rules are as follows:

(1) The priority is to pump as much river water as possible into the off-channel reservoir if river water quality is acceptable and the water level in the river is above the intake.
(2) The second priority is to pump as much river water as possible to the treatment plant to meet water demand.
(3) The third priority is to release water from the off-channel reservoir to the treatment plant when the nitrate concentration in river water is above the drinking water standard or there is insufficient water in the low-head impoundment. If a precipitation event elevates the off-channel reservoir level above its normal pool elevation, the off-channel reservoir water is released to the treatment plant to avoid spills.

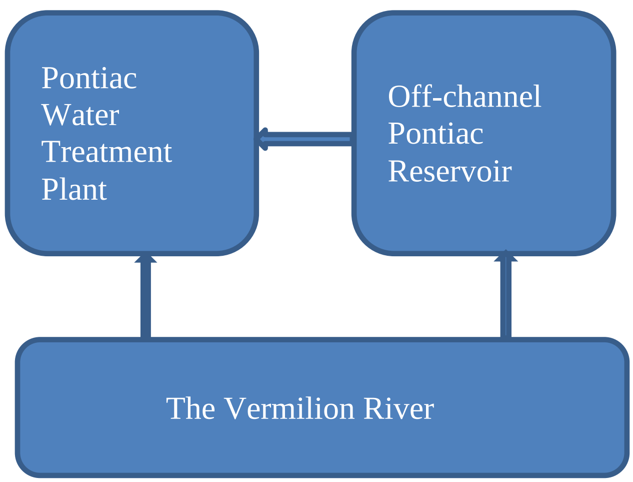


Figure 58. Schematics of the Pontiac public water system

The off-channel reservoir is refilled annually, often between late August and early November, when the water quality and quantity in the Vermilion River is sufficient. The reservoir is usually used to supply water to the water treatment plant during the spring and summer months when the nitrate concentration in the Vermilion River is elevated or the water level in the river is low. The reservoir water is also needed to reduce taste, odor, and elevated ammonia levels in the Vermilion River.

The greatest water supply threat to the Pontiac system occurred during the 1988 drought. The USGS streamflow gage located downstream of the Pontiac intake recorded zero flow for 133 days from July 1 to November 10 of that year, indicating that storage was providing a portion of the community's water use during that time. Sandbags had been added to the crest of the spillway to increase the depth of the pool behind the low-channel dam by roughly 1 foot. This presumably happened at the same time when zero flow was observed at the downstream gage (July 1). But by July 26, the water level had fallen back to the original concrete crest and continued to decline until it reached a minimum of 12 inches below the crest in early September (Knapp, 1988). Pontiac's average water use in 1988 was 2.0 Mgd, but the water use in the summer months during the drought was reported to have exceeded 2.5 Mgd. Of the water used from July 1 to early September (roughly 70 days), an estimated 20 to 25 million gallons (0.3 Mgd) came from in-channel storage, with the remaining primary amount coming from the Vermilion River inflow.

The USGS gage downstream of the Pontiac intake registered zero flow for a few days during the 1953 drought, using only a negligible amount of water from in-channel storage. However, the average water use that year was only 1.1 Mgd (ISWS files). If the water use in 1953 had been 2.0 Mgd with summer rates exceeding 2.5 Mgd (similar to 1988), an estimated 35 million gallons of in-channel storage would have been needed for 117 days (July 23 to November 17), consuming roughly two-thirds of Pontiac's in-channel storage capacity. Thus, when comparable levels of water demand are assumed, the 1953 drought is considered the most severe drought as it would have required greater storage depletion than the 1988 drought.

Hecht (2011) used a water budget model to analyze the performance of the Pontiac system during the 1988 drought assuming that the off-channel storage had been available as an additional supply source. Yields under several different operation scenarios were simulated, including:

1. A "maximum yield," indicating a condition in which water quality has not restricted the available supply such that all of the system's storage is available for withdrawal at the start of the drought's critical period when the river's inflow is insufficient to meet demand. Achieving the maximum yield would essentially require that none of the reservoir water is used for blending such that the facility's ion exchange system is operated whenever the river's nitrates exceed the water quality standard. The system's maximum yield calculated by Hecht (2011) was 3.5 Mgd.
2. Most other scenarios under a variety of management options assume that Pontiac continues to use reservoir water for blending when it is practical to reduce nitrates prior to engaging its ion exchange system (the more expensive treatment option). When some of the storage in their reservoir is used for blending instead of being used as a supplemental supply when the river's flow becomes low, the system's yield declines. If blending is the primary treatment option, Hecht calculated that the yield would typically range from 2.2 to 2.7 Mgd, depending on a variety of management options.
3. The "minimum yield" is essentially created when all of the off-channel storage is used entirely for blending such that it is not available for the drought's critical period when the river's inflow is insufficient to meet demand. The system's minimum yield calculated by Hecht (2011) was 2.2 Mgd.

For most of the blending scenarios that Hecht (2011) examined, at least half of the off-channel reservoir storage is depleted before the river's flow quantity becomes a limiting factor. If IAWC were to reserve half of the off-channel reservoir capacity for supplementing water supply quantity during the 1988 drought, the yield would be roughly 2.7 Mgd. The availability of daily $NO_3$-N data beginning during the 1988 drought was a significant factor in Hecht (2011) choosing that drought for analysis. Additional adjustments to the yield estimates by Hecht (2011) must be considered. Although the 1953 drought is calculated to be the worst drought on record, additional modeling suggests that the estimated yield differences between the two droughts are very small (no more than 0.1 Mgd).

Hecht (2011) described the 90 percent yield as the "pessimistic hydrologic scenario," producing a yield of 1.8 Mgd corresponding to the system's "minimum yield." Because this 90 percent yield estimate falls short of the current 1.88 Mgd average daily demand for Pontiac, the system's drought vulnerability is classified by the ISWS as at-risk. If, however, the IAWC uses less blending (greater use of ion exchange treatment), reserving up to half of the water for supplementing low flow conditions in the river, the 90 percent yield could be as much as 2.2 Mgd with a corresponding ISWS drought vulnerability classification of marginally adequate.

For the Pontiac public water system, both the available streamflow and nitrate concentrations in river water have substantial impacts on the system's yield. Efforts on land and watershed management are encouraged to reduce nitrogen loads into the Vermilion River, which would increase the available water. In addition, the water withdrawal by Pontiac could dry up the Vermilion River downstream of the dam and cause an adverse impact on aquatic ecosystems during drought conditions.

### *4.7.3 Streator Public Water System*

The Streator public water system serves approximately 7500 customers (17,000 persons) in the City of Streator and surrounding areas (Kangley Village and portions of Eagle, Otter Creek, Newtown, and Reading Townships). Streator is a small city with a population of about 14,000, and it is situated along the Vermilion River, about 20 miles downstream of Pontiac and 90 miles southwest of Chicago. The Illinois American Water Company owns and manages the public water system. The Streator public water system has a similar setting as Pontiac; both pump water from a low-head impoundment and use an off-channel reservoir to enhance the water availability either by supplementing water supply when the streamflow is low or blending with river water when water quality in the low-head impoundment is not desirable.

The concrete gravity low-head dam, known as the Streator Dam, was constructed in the late 1920s and is located downstream of the intake. The drainage area upstream of the dam is 1050 square miles. The 15.5 foot tall dam maintains a pool to provide storage of 804 acre feet (262 million gallons) in the low-head impoundment. An estimated 80 percent of the storage behind the dam could be harvested for water supply purposes. In addition, a wooden weir can be installed on the crest of the 185 foot long spillway to increase the pool level by 10 inches. Three pumps with a rated capacity of 9 Mgd and a reliable capacity of 6 Mgd pump water from the river to the water treatment plant. These pumps are also used to transfer water for the off-channel reservoir to the water treatment plant.

The off-channel reservoir, named Lentman Lake or the Streator Reservoir, was originally a clay quarry. It was purchased by the Northern Illinois Water Corporation in 1956 and placed in service as an off-channel reservoir in 1964. Figure 59 shows the aerial view of the reservoir, the Streator Dam, and the water treatment plant. The reservoir is approximately 30 feet deep with a total storage of 613 acre feet that could provide water supply to Streator for about 90 days. A 5 Mgd pump is used to convey water from the river to the reservoir and a backup 4 Mgd pump is maintained in case the 5 Mgd pump fails. When nitrate concentrations in the river are less than 5 mg/L, water is pumped from the river to the reservoir. The reservoir water is used to enhance water availability during a low flow period or when water quality in the river is not satisfactory because of high concentrations of nitrate, taste- and odor-causing compounds, or ammonia.


Figure 59. Aerial view of the dam, reservoir, and water treatment plant of the Streator public water system

The Illinois American Water Company uses watershed-based best management practices (BMPs) in conjunction with optimized usage of the off-channel reservoir to manage nitrate levels in the effluent water of the water treatment plant. This approach has mostly been successful, but the nitrate concentrations in the river were extremely high in the spring and summer of 2001. Therefore, a temporary reverse osmosis (RO) system was installed to treat the extremely high nitrate concentrations. The high cost of the RO system led to the installation of an ion exchange system of treatment capacity of 4.8 Mgd in 2002 to remove nitrate from the river water when needed.

Concerns regarding the adequacy of the Vermilion River to provide a consistent supply for Streator's needs were first reported in the summer of 1914. Soon thereafter, a USGS gage was installed immediately downstream of the Streator river withdrawal. From 1914 to 1927, that gage recorded zero flow in two years (1920 and 1923), and low flows of less than 1 Mgd occurred in nine years. The average water withdrawal at Streator in these years was about 2 Mgd. The USGS gage at Streator was removed in 1930; thus, no river flow information at the withdrawal site is available for later drought periods. USGS gages have since been operated at Lowell (21 miles downstream) from 1931 to 1970 and near Leonore (14 miles downstream) from

1971 to the present. However, the low flow amounts at both of these gage locations are considerably greater than at Streator.

In the 1950s, the average water withdrawal at Streator was reported to be about 2.5 Mgd. During the fall of 1953 (a major drought), Streator's water use was substantially greater than the natural flow in the river, causing the water level behind the channel dam to fall 32 inches below its spillway crest by November 9. The flow measured at the USGS downstream at Lowell suggests that low flow concerns at Streator may have continued into January 1954. Continuing drawdown behind the dam before recovery is suspected to have occurred for at least a 100-day period from early August to mid-November, if not longer.

During that drought in 1988, the average water withdrawal at Streator was almost 4.0 Mgd with a peak usage of 4.6 Mgd, and the pool level behind the channel dam fell from June 20 to August 20 to a maximum drawdown of 36 inches below its spillway crest. The water level in the off-channel reservoir had fallen 5 feet, roughly corresponding to a loss of 40 million gallons. Another 30 million gallons of supplemental flow in the Vermilion River was provided by dewatering a rock quarry located 14 miles upstream near Cornell. In all, over a 61-day period, Streator's water use has exceeded that natural flow in the Vermilion River by an estimated 200 million gallons (an average of 3.3 Mgd).

Although Streator's loss in storage during the 1988 drought was substantially greater than that in 1953, much of that loss was associated with the city's higher average water use in 1988. The calculated natural low flow of the Vermilion River is noticeably lower for 1953. If the average water use in 1953 had been as high as 4.0 Mgd, the community is estimated to have experienced a water shortage in which extraordinary water restrictions would have been necessary to prevent the depletion of the available water stored behind the channel dam.

A water budget model for the Streator supply system developed by the ISWS examined drought vulnerability during both the 1953 and 1988 droughts assuming the available present-day sources. The yield results for the two droughts are similar but slightly lower for the 1953 drought. Model calculations indicate that the 1953 maximum yield assuming no water quality restrictions (and availability of the off-channel storage to supplement low river flow) would be 5.1 Mgd. Assuming that the off-channel storage is only used for water quality blending, the minimum yield is calculated to be 3.7 Mgd. When data inaccuracies are considered in the modeling process, the Y90 minimum yield when off-channel storage is used entirely for blending is 3.1 Mgd. Because the Y90 minimum yield is greater than the current and projected average water use (1.98 and 1.78 mgd, respectively) for Streator, the ISWS drought vulnerability classification considers the system to be an adequate supply.

Note that the yield analysis did not consider the in-stream ecosystem water demand. Even with the ion exchange system, the water demand may cause unacceptable stress on aquatic ecosystems as it may decrease the streamflow significantly during drought conditions. A fish kill in the Vermilion River in 2012 demonstrated the impact on ecosystems during drought conditions (Figure 60). Due to high temperatures, low dissolved oxygen, and extremely low flow, thousands of fish were killed in the Vermilion River below the Streator Dam on July 12, 2012 (Barichello, 2012). The river was dry in some portions even though the water supply was maintained. These effects emphasize the stresses that the Streator public water system is facing. In addition, it reveals the potential competition between human and ecosystem needs. To quantify in-stream ecosystem needs is a challenge, especially when on-site data of aquatic habitat and aquatic species are limited (Zhang et al., 2016). The yield would be lower if in-stream ecosystem needs are considered or a protected minimum flow is specified.

Figure 60. Fish kill in the Vermilion River below the Streator Dam on July 12, 2012 (Barichello, 2012)

### *4.7.4 Peoria Public Water System*

The Peoria public water system serves a population of about 120,000 within the city limits and about 25,000 outside city limits. The system is owned and operated by Illinois American Water. The total system water demand in 2017 was 20.09 Mgd. The historic water demand by the Peoria public water system is shown in Figure 61. On average, 37 percent of the water supply is water withdrawn from the Illinois River. The surface water demand has been ranging from 5 to 10 Mgd for the past 30 years.

The observed minimum streamflow in the Illinois River at Marseilles and Kingston Mines are 460 and 600 cfs, respectively. The current and projected surface water demand for Peoria is only about 2 percent of the minimum streamflow. As noted, the system also primarily uses groundwater, and uses increasing amounts during periods when surface water is not preferred on account of water quantity or quality concerns. As a result, the available surface water is considered sufficient to meet the surface water demands of the Peoria system.

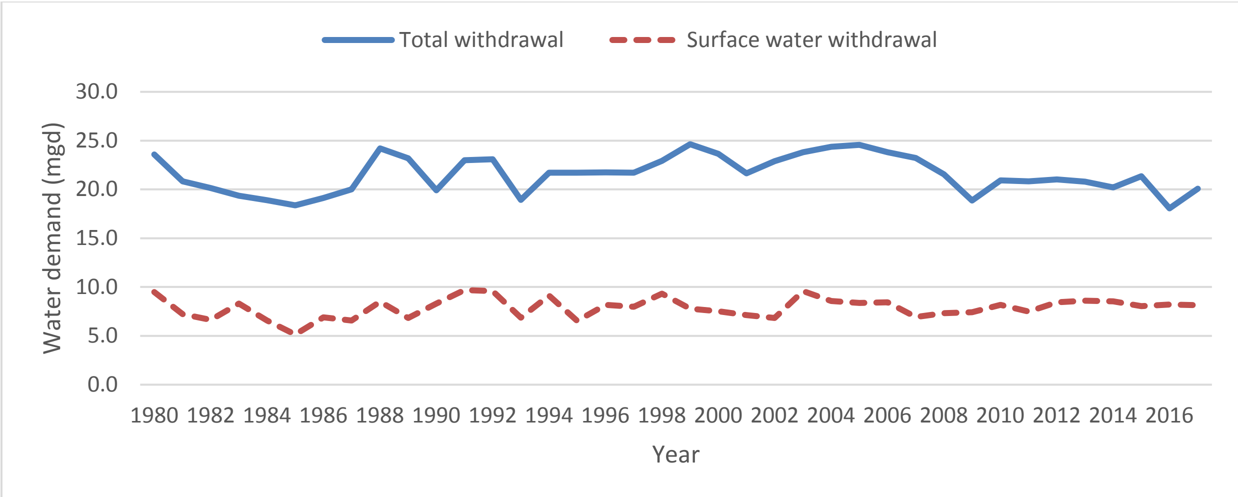

Figure 61. Total water demand and surface water withdrawal for Peoria public water system

## 4.8 Illinois Streamflow Assessment Model (ILSAM)

### *4.8.1 ILSAM*

The Illinois Streamflow Assessment Model (ILSAM) is a watershed management information tool designed by the ISWS to provide resource managers and planners with information on streamflow frequencies along major streams within a watershed of interest. ILSAM is applicable for major streams that have upstream contributing drainage areas of at least 10 square miles.

In ILSAM, the streamflow can be separated into two components: (1) unaltered flow conditions as influenced primarily by the climate, topography, hydrogeology, and prevailing land-use conditions in the watershed, and (2) modifications to flow conditions by human activities that produce a quantifiable change in the temporal response of flow from the watershed. In Illinois, the quantifiable flow modifiers primarily include withdrawals, effluent discharges, and reservoirs. The ISWS developed a suite of approaches to characterize the flow modifiers and develop unaltered flow estimates for Illinois. Complete descriptions of the methods used in ILSAM were presented in several earlier reports (Knapp, 1985, 1988, 1992, Knapp and Russell, 2004, Knapp et al., 1985). ILSAM produces estimates of flow statistics for 154 different streamflow parameters for any selected stream location. These streamflow statistics fall into four categories: mean flow, flow duration frequency, low flow, and drought flow.

For gages that do not have a complete record for the base period of record, the streamflow parameters are adjusted using record-extension techniques. Record extension is an important aspect in developing flow estimates. Otherwise, flow characteristics from a gage with a record from 1940 to 1963 might look entirely different and inconsistent with those from a nearby gage with a record from 1991 to 2014, simply because of differences in precipitation between the two periods.

The flow modifiers, including withdrawals and effluents in the Middle Illinois, are analyzed with the IWIP database and the National Pollutant Discharge Elimination System (NPDES) effluent discharge database of the IEPA to characterize the flow modifiers for each gage. Then streamflow parameters under unaltered conditions are computed by excluding the flow modifiers. For details of the these steps, readers are referred to various ISWS reports (Knapp and Russell, 2004, Knapp et al., 1985).

### *4.8.2 Middle Illinois ILSAM Model for Gaged Sites*

The Middle Illinois ILSAM model provides streamflow statistics for all tributary streams to the Illinois River (drainage areas of 10 square miles or greater) upstream of the Tazewell-Mason County line, except for the Vermilion River. A separate model for the Vermilion River watershed was originally developed in 2003 and has been modified to include updated information (through 2014) on effluent discharges and withdrawals in that watershed. The USGS streamflow gages and pertinent information in the Middle Illinois are shown in Table 11. Smaller portions of the Middle Illinois region are also contained within the Fox, Spoon, and Mackinaw River watersheds, and ILSAM models were previously developed or revised in 2008, 2004, and 2003, respectively. The Middle Illinois ILSAM model extends to two major areas beyond the region's boundaries, including results for (1) the entire watershed of Bureau Creek and (2) Illinois River tributaries located in Grundy and Kendall Counties. Table 16 shows the annual average flow and 7-day, 10-year low flow for selected locations estimated by the Middle Illinois ILSAM.

Database components for the Middle Illinois ILSAM model include the following processed hydrologic information: 1) flow frequency calculations for 19 USGS streamgages in the region (Table 16); 2) frequency estimates for 30 effluent discharges in the region (25 community treatment plants and 5 industrial discharges); and 3) regional equations for estimating flow frequency at ungaged stream locations. Pertinent watershed characteristics (drainage area, subsoil permeability, and net precipitation) were calculated for 841 locations in 100 different streams in the region.

Monthly effluent discharge data provided by the Illinois Environmental Protection Agency (IEPA) were used as input to calculate the discharge-frequency relationship associated with all major effluents in the region. The effluent discharges selected for input in ILSAM are generally those that have an average discharge of 100,000 gallons per day (gpd) or greater and/or a low flow discharge of 32,000 gpd (0.05 cfs). The method used to transform monthly data discharge to flow frequency estimates (flow duration and low flows) was developed by Knapp (1990) and has been applied to all ILSAM models. There are no known water withdrawals from tributary streams; all known withdrawals are from the Illinois River mainstem or the Vermillion River, which was not included in the model.

Based on the available streamflow data, the 75-year record (1940-2014) is used as the base period for the Middle Illinois for the study. For gages having shorter gaging records, a record extension technique developed in previous ILSAM studies was applied to prepare flow estimates that represent the expected flow frequency characteristics for the entire 75-year base period.

For each extended gage record, flow frequencies are estimated for both present and unaltered flow conditions. The type of treatment for analyzing gage records is dependent on how well the USGS flow record relates to either the present or unaltered flow. For six gaging records in the region, there has been little or no modification of the streamflow (by way of effluent discharges or reservoirs), such that the present and unaltered flows are considered to be identical and represented by the gaging record. In many other cases, the streamflow has been moderately modified by the effluent from a small town or city that has experienced little change in population over the past 50 years. In these cases, the USGS gaging record is often considered equivalent to the present flow condition. The calculation of unaltered flow in these cases involves iteration within the model calibration process to determine the relationship between unaltered and present flows.

The most complicated cases involve streamflow records that are greatly modified or where the amount of modification has changed substantially over the course of the flow record. For the Middle Illinois model, the flow records on Farm Creek, which are affected by flood control reservoirs, fall in this category. For these cases, regional flow equations were initially used as input to estimate the effect of the reservoirs on modified flow conditions. From this, unaltered flow estimates were then progressively adjusted until the resulting modified flow estimates were like the flow frequencies from the USGS gage records on Farm Creek. The relationship between unaltered and modified flows downstream of reservoirs was estimated using an ILSAM process developed by Knapp (1988). With other gage records where the relationship between unaltered and modified flows changes substantially over time, it can be necessary to separately model the changes over time of the flow modification and disaggregate these changes from the daily flow record before analyzing (or extending) the flow frequency at that gage.

Table 16. Estimated Annual Average Flow and 7-day, 10-year Low Flow in cfs for Selected Locations Using the Middle Illinois ILSAM

| Site Name | Average Flow | | 7-Day, 10-Year Low Flow | |
|---|---|---|---|---|
| | Present Flow | Unaltered Flow | Present Flow | Unaltered Flow |
| Aux Sable Creek near Morris | 150 | 147 | 1.0 | 0 |
| Mazon River near Coal City | 365 | 363 | 0 | 0 |
| Big Bureau Creek at Princeton | 148 | 146 | 0.67 | 0 |
| West Bureau Creek at Wyanet | 58 | 58 | 0 | 0 |
| Big Bureau Creek at Bureau | 357 | 345 | 7.97 | 0 |
| Crow Creek (West) near Henry | 44 | 44 | 0 | 0 |
| Crow Creek near Washburn | 75 | 74 | 0 | 0 |
| Senachwine Creek at Chillicothe | 57 | 57 | 0 | 0 |
| Ackerman Creek at Farmdale | 6.8 | 6.8 | 0 | 0 |
| Kickapoo Creek near Kickapoo | 80 | 80 | 0.25 | 0.1 |
| Kickapoo Creek at Peoria | 208 | 207 | 0.90 | 0.7 |

### *4.8.3 Middle Illinois ILSAM Model for Ungaged Sites*

Regional flow (regression) equations are used to estimate the unaltered flow conditions at ungaged sites. From previous ILSAM modeling efforts, sets of equations exist for six hydrologic regions in Illinois; each set includes coefficients for estimating flow for 154 streamflow frequency parameters at ungaged locations. The set of regression coefficients for ILSAM regions has typically been developed using flow records from 10 to 20 gages within that region. However, for one hydrologic region in the Rock River Basin (Knapp and Russell, 2004) developing a set of equations using only seven gages was necessary.

In addition to the potential use of the six existing sets of regional equations, it was initially expected that the Middle Illinois Region would need a seventh set of equations to represent streams that drain the bluff watersheds along the Illinois River. An examination of the USGS streamflow records for these bluff areas discovered that their flow characteristics did not follow a well-defined collective pattern. But roughly half of the streams had flow frequencies similar to that from an existing equation set representing the Springfield Till Plain, a hydrologic region of south-central Illinois. The common characteristic between streams in the Springfield Till Plain and the bluff watersheds is that their flow range is expanded, with higher high flows and lower low flows. Most of the streams located west of the Illinois River (Peoria, Stark, and western Marshall Counties) had flow characteristics similar to the Spoon River hydrologic region, whereas several gaged watersheds to the east of the Illinois River had flow characteristics similar to parts of the Vermilion and Fox River watersheds (the Bloomington Ridged Plain hydrologic region).

### *4.8.4 Calibration of the Middle Illinois ILSAM model*

One of the major objectives of the ILSAM modeling is to develop seamless and hydrologically consistent estimates of flow characteristics along each modeled stream. Inconsistencies would generally be described as jumps or drops in a flow parameter when moving upstream or downstream that cannot be explained by hydrologic principles. On ungaged streams, the unaltered flows calculated from the regional regression equations have been specifically designed to avoid such inconsistencies. On a stream with one or more gages, however, flow estimates from individual gages or from the regional flow equations may potentially be noticeably different from each other.

Flow frequency estimates from USGS gage records are usually moderately different from, and ordinarily supersede, the corresponding estimates for that location derived from the regional equations. To avoid abrupt differences in flow estimates between gaged and ungaged sites on the same stream, algorithms within ILSAM provide a mechanism to gradually adjust the ungaged equation values at locations approaching the streamgages from either the upstream or downstream side to match the calculated results at the gage. Thus, these algorithms are designed essentially to self-calibrate the model to match gage observations. However, the algorithms can result in inconsistencies when dealing with zero flows, for example, when the gage analysis produces a non-zero flow estimate, but the equations indicate that the streamflow value should be zero, or vice versa. In these cases and others where there is a substantial difference between the regional equations and gage estimates, a more holistic and powerful calibration technique is used that involves modifying the subsoil permeability coefficient for that stream.

The subsoil permeability, as represented by the permeability of the lowest layer within a given soil type, has been shown in previous ILSAM modeling studies to be a good indicator of the movement of shallow groundwater to a stream during extended dry (low flows) conditions. In the ILSAM database, the average subsoil permeability for any given stream location is an area-weighted average for all soils located within that contributing drainage area, computed using soil permeability values contained in the U.S. Department of Agriculture's Soil Survey Geographic (SSURGO) database.

The SSURGO data are by far the best available information on soil permeability, but there are two basic limitations regarding its use with ILSAM. First, the permeability value for any soil is characterized using a broad range; for example, a moderately well-drained soil can be expected to have a permeability in the range of 0.6 to 2.0 inches per hour (in/hr). Thus, although the permeability value is a defined physical characteristic, it is not a measured value specific to each particular soil type. In this example, the ILSAM database would typically adopt a mid-range value of 1.3 in/hr for this soil. Second, when located on a ridge or other topographically high situation, sandy soils may not retain water and thus may not contribute to baseflow. Though regions with highly permeable sandy soils are typically associated with very high levels of baseflow in streams. For the Senachwine Creek watershed in Peoria County and the Mazon River watershed in eastern Grundy County, the permeability values for selected sandy types were reduced because observed flows at a nearby USGS gage indicated that these soils provided little or no baseflow to that gage.

While applying the ILSAM model to several gaged watersheds in the western portion of the Middle Illinois region (Peoria, Marshall, and Bureau Counties), it was observed that all of the streamgages had lower baseflow levels than what would be expected given the calculated soil permeability and hydrologic region. A dominant soil type in all these regions is the Osco silt loam. Through trial and error, it was determined that the regional equations and gaging flow values were much more consistent when the Osco soil type was assigned a lower subsoil permeability of 0.8 in/hr, still within the range identified in SSURGO. In the same manner, in previous ILSAM studies the permeability of the Drummer silty clay loam and similar tile-drained soils in central Illinois have been adjusted to 0.6 in/hr.

# 5 Summary and Recommendations

## 5.1 Summary

### *5.1.1 Water Demands*

Water demand for thermoelectric power generation dominates present and future demand in the region. Currently, three thermoelectric power plants are located in the Middle Illinois WSPR, all adjacent to the Illinois River. The current water demand for these three plants is an estimated 588 Mgd. This water, which is surface water used for cooling, is largely returned to its source after use. An estimated 6 to 7 percent of the total demand is evaporated. Future demand for thermoelectric power generation will depend strongly on cooling system design and gross generation capacity of operating power plants in the region. Our scenarios of maximum demand assume that no new power plants will be built and that present power plants will continue to operate at current levels until 2060, with water demand remaining at 588 Mgd.

The other four major water use sectors, public supply, self-supplied domestic demand, self-supplied industrial and commercial (IC) demand, and self-supplied irrigation, livestock, and environmental (ILE), accounted for approximately 210 Mgd in 2010, with self-supplied IC demand accounting for 150 Mgd of this total. We estimated the future demand for these sectors out to 2060 considering three plausible scenarios of socioeconomic and weather conditions: (1) current-trends (CT); (2) less resource-intensive (LRI); and (3) more resource-intensive (MRI). From 2010 to 2060, total demand for these four sectors increases to 322 Mgd under the CT scenario, 242 Mgd under the LRI scenario, and 428 Mgd under the MRI scenario. Most of the increase in total demand under all scenarios, but in particular the CT and MRI scenarios, is due to increases in self-supplied IC demand.

### *5.1.2 Groundwater*

Significant water resources are available to meet demands in the Middle Illinois WSPR. Most of the region can utilize groundwater resources from two major aquifer systems, shallow sand and gravels and sandstones. The sand and gravel aquifers in the region can be productive, particularly along the Illinois River Valley, but also in western Woodford County, eastern and western Livingston County, and northwestern LaSalle County. Sand and gravel aquifers in the Illinois River Valley are connected to the river, and groundwater levels fluctuate in response to river stage. The aquifers along the Illinois River are also vulnerable to surface contamination, especially nitrate. Arsenic, which is a naturally occurring contaminant, can be elevated in sand and gravel aquifers. In addition, elevated levels of chloride are observed in the Peoria region, probably from road salt runoff.

Model simulations indicate that the sand and gravel aquifers should be sufficient to meet their projected demands, at least on a regional scale. Local issues in the sand and gravel aquifers may still occur because of the tight clustering of well fields, the variable quality and saturated thickness of the sands and gravels along the Illinois River, variability of the Illinois River stage, and elevated chloride concentrations.

Two methods were used to assess the vulnerability of sand and gravel aquifers for water supply. First, the groundwater flow model was used to determine head declines in sand and gravel aquifers out to 2060. The cities that are predicted to have the largest head declines are

Washburn, Lowpoint, Rutland, Congerville, and Ransom. However, Ransom started purchasing water from Illinois American in 2016, with water originating from Streator. For the other four facilities, these declines do not necessarily mean that the unconsolidated materials will no longer be useable, but there may be a need for new and existing shallow wells to be drilled deeper as the shallow water table declines.

The second method used current demands and size of municipalities along with aquifer transmissivity to estimate risk. Using this method, LaSalle, Sparland, Lostant, Rutland, Secor, Cornell, Dwight, Campus, and Fairbury were identified as having the highest risk in the region. Except for LaSalle, these are small cities using relatively nonproductive aquifers for their water supplies. Susceptibility to surface contamination was also assessed based on the proximity of a municipality using shallow groundwater to a recharge source, and LaSalle and Sparland were identified as being sensitive to both future water demand and water quality concerns.

The deeper Cambrian-Ordovician sandstone aquifer system is productive throughout the region, although its usefulness decreases farther south because of increasing depth and salinity. Pumping over the past 35 years has resulted in a modest head decrease of 25 to 50 feet in the sandstone aquifer in most of the region. No water supply issues related to this decline have been reported to the ISWS.

The major factor potentially affecting supply in the sandstone aquifers is the risk of desaturation of the St. Peter Sandstone. In most of the region, the sandstone is projected to have enough water to satisfy demands to 2060. The area of greatest concern is in east-central LaSalle County along the Illinois River. The sandstone in this region does not have as strong of a hydrologic connection to the Illinois River as is observed in the western part of the county. New industrial growth in this region might put additional stress on water supply, which was not simulated in the model, and could cause additional head declines by 2060, putting the St. Peter Sandstone at risk of going dry locally, and reduce the productivity of wells in the lower Ironton-Galesville.

Northern LaSalle County is heavily influenced by withdrawals in Grundy, Will, and Kendall Counties to the north. Many communities in northeastern Illinois are likely to switch sources from the sandstone aquifers to surface water in the near future, which will impact sandstone heads in the Middle Illinois WSPR, especially in LaSalle County. Thus the future scenarios shown in this report for both the St. Peter and Ironton-Galesville aquifers should be viewed as worst-case scenarios. Sandstone heads in the southern part of the Middle Illinois WSPR may be influenced by as much as 50 feet because of new withdrawals that will commence in Bloomington by 2020, but these withdrawals are not great enough to put the St. Peter at risk in this region.

The main water quality concern in the sandstone aquifer, other than salinity, is radium, whose concentration is above the drinking water standard in most of the wells. Fluoride levels are also naturally elevated in many wells, often greater than the secondary drinking water standard (2 mg/L), but lower than the primary standard (4 mg/L).

A total of 26 public facilities in the Middle Illinois WSPR have a single production well for their water supply. Water supplies at these facilities are by definition at risk because if their well failed, they would not be able to distribute water to their customers. As recently as 2017, Cedar Point’s 105-year-old well failed, and they were without a reliable water supply for three months.

### 5.1.3 Surface Water

The primary surface water sources in the Middle Illinois are the Illinois and Vermilion Rivers. The Illinois River generally provides sufficient and reliable water supply for public water supply and industry. Peoria withdraws 37 percent of its water supply from the Illinois River, which equals approximately 2 percent of the minimum flow in the Illinois River near Peoria. Thus the Illinois River is sufficient to meet Peoria's surface water demand for public water supply. Thermoelectric power plants also withdraw large amounts of water from the Illinois River, most of which is directly returned to the river. But any new thermoelectric power generation cooling water withdrawals from the Illinois River could potentially be restricted because of protected low flows (set by IDNR permit) or higher water temperatures during drought conditions.

The Vermilion River provides water supply for the Pontiac and Streator public water systems. These systems are enhanced by off-stream reservoirs and ion exchange systems for both water quantity and quality purposes. The Pontiac system is classified as at risk and would be reclassified as marginally adequate if greater use of ion exchange treatment is adopted. The Streator system is considered an adequate supply. However, the Vermilion River downstream of Pontiac and Streator could be dried up by withdrawals from the two cities and thus cause adverse impacts on instream aquatic ecosystems. Flows in other tributaries in the Middle Illinois could be a very low level or zero. Therefore, they are not suitable for water supply.

Changes in the Lake Michigan diversion have had substantial impacts on low flows in the Illinois River. With the decreasing diversion from Lake Michigan, the lowest flow amounts along the Illinois River are expected to decrease again in the near future. Although these changes are not limiting with regard to the availability of flow for most water supply needs, they can pose challenges for low flow and protected flow management of the river.

Operation of the powerhouse at Lockport, which is upstream of the Middle Illinois, during low flow conditions can create sizeable fluctuations in the amount of water released downstream. At each successive downstream lock and dam on the Des Plaines and Upper Illinois Rivers, operations by the USACE appear to effectively pass these fluctuations downstream while attempting to maintain the target pool level behind each dam. An existing unsteady flow routing model for the Illinois River was used to replicate these operating conditions with a specific focus on the Marseilles Dam and pool within the WSPR. This model was also used to investigate the impacts related to selected alternative operation scenarios. These scenarios suggest that there is the potential to incrementally attenuate the low flow fluctuation at each successive downstream dam through modest changes in pool-level management. This study did not attempt to evaluate the possibility that modifications could also be made at Lockport to reduce the amplitude of the flow fluctuations.

## 5.2 Recommendations for Future Work

### 5.2.1 Water Demands

As new water use data are reported to the ISWS, the demand scenarios should be evaluated to understand which of them reflect the actual growth. This should be conducted on both a regional and local scale. Thermoelectric power generation is the dominant water user in the region, thus in-depth analysis of the water-energy nexus in the region is warranted for water supply planning purposes.

### 5.2.2 Groundwater

Sand and Gravel Aquifers: Since the regional model cannot capture many of the local-scale complexities, we recommend in future water supply planning for the Middle Illinois WSPR that a refined model of the sands and gravels along the Illinois River be developed, particularly in the Peoria region. Such a model would improve simulation of surface-groundwater interactions, well drawdown interference, and contaminant transport. A synoptic measurement of water levels and chloride or nitrate concentrations focused on the sands and gravels along the Illinois River would also provide valuable data to calibrate such a refined model.

Sandstone Aquifers: First, after consulting with the Middle Illinois RWSPC, it is recommended to develop a new future scenario that accounts for the expected locations of new industrial demands along the Illinois River. This will be supplemented with modified future scenarios for Northeastern Illinois, accounting for the water supply plans of communities and industries in that region. Second, different conceptualizations of the hydrologic behavior of geologic structures should be examined with the groundwater flow model to test their impact on groundwater supply. Finally, withdrawals from Iowa should be incorporated into the model to test if they influence the simulations in the Middle Illinois WSPR, which is possible given the far-reaching impacts of sandstone demands.

### 5.2.3 Surface Water

During extreme drought conditions, the observed streamflows along the Illinois River show some inconsistency. The impact of the evaporation from Senachwine Lake, Upper Peoria Lake, Peoria Lake, and other waterbodies in the region on the low flows need to be examined in more detail. To better understand low flow conditions in the Illinois River, it is valuable to explore water-level management of Peoria Lake. The Lake Michigan diversion is expected to be decreased and surface water withdrawals in the Kankakee watershed will be increased. A watershed hydrologic model that can simulate these impacts will allow us to better understand how the low streamflows in the Illinois River change in the future. The Middle Illinois ILSAM results need to be incorporated into a GIS-based user-friendly platform to better disseminate the results.

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## Appendix A. Well Water Quality Sampling

A total of 21 samples were collected from wells finished in the St. Peter Sandstone in the Middle Illinois Region in 2015 (Figure A1 and Table A1). Many of the wells are open to other units above and below the St. Peter, but the St. Peter is considered to be the most transmissive unit in this region. The samples came from 17 community supply wells, two commercial wells, one state park well, and one domestic well. The wells were sampled between June and August 2015. All of the community and commercial wells were being pumped prior to sampling. A multi-sonde (Hydrolab MS5) was used to measure field parameters (water temperature, pH, specific conductance [SpC], oxidation-reduction potential [ORP], and dissolved oxygen [DO]). Once these parameters stabilized, values were recorded and water samples collected. Water was passed through a 0.45 µm filter capsule prior to collection. Water samples were collected in separate bottles or vials for inorganic constituents (anions, cations/metals, alkalinity, ammonium-nitrogen [$NH_4$-N]), dissolved organic carbon (DOC), and the stable isotopes of water ($\delta^{18}O$, $\delta D$), sulfate ($\delta^{34}S$, $\delta^{18}O$), dissolved inorganic carbon ($\delta^{13}C$), strontium ($^{87}Sr/^{86}Sr$), and various radioisotopes, $^{226}Ra$, $^{228}Ra$, $^{222}Rn$, $^{238}U$, and $^{234}U/^{238}U$. Samples for gas analysis were collected in IsoFlasks® (Weatherford, Inc.) following manufacturers' instructions.

Complete inorganic chemistry and DOC analyses were conducted at the ISWS Public Service Laboratory (Champaign, IL) using standard analytical procedures. Anions were determined by ion chromatography, cations/metals by inductively coupled plasma-atomic emission spectrometry, alkalinity by titration, DOC by combustion, ammonium by semi-automated colorimetry, and arsenic by stabilized temperature graphite furnace atomic absorption (arsenic concentrations were always below detection, 0.79 µg/L). TDS values were calculated by summing the concentrations of all dissolved constituents. Stable isotope analyses except for Sr were prepared at the ISGS Isotope Laboratory (Champaign, IL) and analyzed at Isotech Laboratories (Champaign, IL). Samples for $\delta^{18}O$ and $\delta D$ were measured by cavity ring-down spectroscopy on a Picarro L2130-i isotopic water analyzer. Long-term analytical precision for $\delta^{18}O$ is ±0.2‰ and $\delta D$ is ±1‰, with values reported relative to Vienna Standard Mean Ocean Water (V-SMOW). Strontium isotopes were prepared using an Eichrom Sr-spec resin for separating Sr from other cations. The samples were analyzed using a Nu Plasma HR multicollector inductively-coupled plasma mass-spectrometer at the University of Illinois at Urbana-Champaign Department of Geology Isotope Hydrogeology and Geochemistry Laboratory. Gas analysis ($CH_4$, $C_2H_6$, $C_3H_8$) was done at Isotech Laboratories (Champaign, IL). Samples for U analysis were prepped and analyzed at the University of Illinois at Urbana-Champaign Department of Geology Isotope Hydrogeology and Geochemistry Lab. Radium and $^{222}Rn$ analyses were done at Eaton Analytical (South Bend, IN).

Analytical results are shown in Table A2 and Table A3.

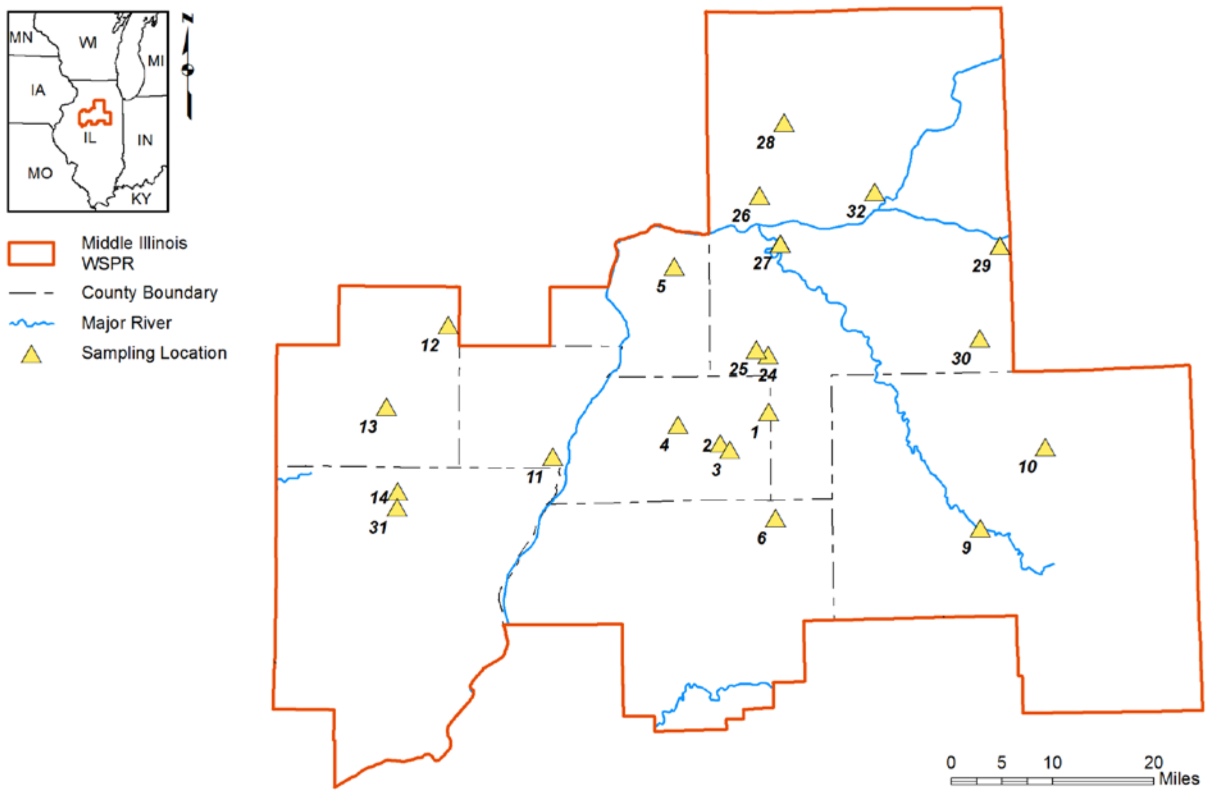


Figure A1. Locations of wells open to the St. Peter Sandstone sampled in 2015. Wells identified by sample number (see Table A1).

Table A1. St. Peter Wells Sampled in the Study

| Sample # | ISWS P No. | IEPA well No. | Owner | Well # | County | Depth (ft) | twn | rng | sec | Sample Date |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 410061 | 00824 | Wenona | 6 | Marshall | 1910 | 30N | 01E | 24 | 6/24/2015 |
| 2 | 407843 | 31316 | Toluca | 3 | Marshall | 1842 | 29N | 01E | 05 | 6/24/2015 |
| 3 | 407842 | 31315 | Toluca | 2 | Marshall | 1874 | 29N | 01E | 05 | 6/24/2015 |
| 4 | 407858 | 31319 | Varna | 2 | Marshall | 1870 | 30N | 01W | 28 | 6/24/2015 |
| 5 | 411001 | 01483 | Granville | 4 | Putnam | 1800 | 32N | 01W | 09 | 6/24/2015 |
| 6 | 409697 | 00132 | Minonk | 3 | Woodford | 1902 | 28N | 02E | 07 | 6/30/2015 |
| 9 | 402486 | | commercial well | | Livingston | 2005 | 28N | 05E | 21 | 6/30/2015 |
| 10 | 410074 | 00666 | Odell | 4 | Livingston | 1935 | 29N | 06E | 10 | 6/30/2015 |
| 11 | 407822 | 31331 | Hopewell | 5 | Marshall | 1775 | 12N | 09E | 27 | 7/6/2015 |
| 12 | 411837 | 01657 | Bradford | 3 | Stark | 2052 | 14N | 07E | 23 | 7/6/2015 |
| 13 | 408696 | 31361 | Wyoming | 1 | Stark | 1557 | 12N | 06E | 01 | 7/6/2015 |
| 14 | 446340 | 01914 | Princeville | 4 | Peoria | 1667 | 11N | 07E | 18 | 7/6/2015 |
| 24 | 405497 | 01165 | Lostant | 5 | LaSalle | 1895 | 31N | 01E | 24 | 7/14/2015 |
| 25 | 406985 | 11477 | Lostant | 4 | LaSalle | 1881 | 31N | 01E | 24 | 7/14/2015 |
| 26 | 421117 | | private well | | LaSalle | 300 | 33N | 01E | 02 | 7/14/2015 |
| 27 | 435265 | | Matthiessen State Park | 1 | LaSalle | 205 | 33N | 02E | 29 | 7/14/2015 |
| 28 | 421988 | | commercial well | | LaSalle | 180 | 35N | 02E | 32 | 7/22/2015 |
| 29 | 411039 | 01422 | Country Acres MHP | 3 | LaSalle | 540 | 33N | 05E | 36 | 7/22/2015 |
| 30 | 406994 | 11515 | Ransom | 4 | LaSalle | 812 | 31N | 05E | 16 | 7/22/2015 |
| 31 | 408208 | 50138 | Princeville | 3 | Peoria | 1680 | 11N | 06E | 24 | 8/11/2015 |
| 32 | 407066 | 11538 | Oaklane Subd | 1 | LaSalle | 287 | 34N | 03E | 35 | 8/11/2015 |

Table A2. Field Parameters and Major Ions for Sampled Wells. Results in mg/L unless otherwise specified

| Well # | Temp (°C) | pH | SpC (µS/cm) | ORP (mv) | Ca | K | Mg | Na | Alkalinity ($CaCO_3$) | $F^-$ | $Cl^-$ | $SO_4^{2-}$ | Fe | Mn | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 22.6 | 7.41 | 2390 | 55 | 58.3 | 16.2 | 25.5 | 402 | 261 | 1.55 | 470 | 188 | 0.837 | 0.0174 | 927 |
| 2 | 23.9 | 7.45 | 2339 | 92 | 54.7 | 15.0 | 23.0 | 401 | 246 | 1.44 | 438 | 220 | 0.322 | 0.0030 | 910 |
| 3 | 24.0 | 7.49 | 2672 | 115 | 50.8 | 14.3 | 21.5 | 481 | 251 | 1.58 | 537 | 224 | 0.211 | 0.0022 | 1008 |
| 4 | 20.0 | 7.55 | 6498 | 43 | 33.1 | 14.6 | 14.2 | 1298 | 447 | 2.70 | 1766 | 164 | 1.02 | 0.0061 | 2275 |
| 5 | 20.2 | 7.32 | 1750 | 129 | 57.1 | 14.1 | 23.7 | 279 | 258 | 1.17 | 299 | 144 | 0.346 | 0.0031 | 704 |
| 6 | 22.7 | 7.46 | 2694 | 115 | 52.9 | 15.0 | 20.5 | 496 | 271 | 2.04 | 547 | 236 | 0.222 | 0.0049 | 1045 |
| 9 | 20.2 | 8.26 | 1857 | -39 | 47.7 | 19.0 | 27.6 | 333 | 280 | 1.45 | 435 | 34.9 | 0.763 | 0.0250 | 743 |
| 10 | 20.3 | 7.17 | 2372 | -17 | 63.1 | 19.9 | 29.1 | 402 | 287 | 1.62 | 492 | 144 | 0.260 | 0.0125 | 932 |
| 11 | 22.7 | 7.52 | 1990 | 60 | 39.8 | 12.3 | 14.9 | 368 | 234 | 1.93 | 225 | 388 | 0.351 | 0.0044 | 830 |
| 12 | 20.9 | 7.21 | 2585 | 89 | 75.1 | 16.5 | 29.6 | 425 | 239 | 1.16 | 529 | 236 | 0.826 | 0.0062 | 1043 |
| 13 | 19.5 | 7.36 | 1961 | 129 | 43.8 | 13.5 | 17.7 | 354 | 238 | 1.71 | 279 | 300 | 0.106 | <0.0015 | 806 |
| 14 | 22.6 | 7.27 | 2448 | 122 | 76.1 | 16.1 | 30.8 | 430 | 223 | 2.02 | 199 | 707 | 0.238 | 0.0030 | 1174 |
| 24 | 22.5 | 7.33 | 2740 | 103 | 73.1 | 15.7 | 32.2 | 446 | 241 | 1.35 | 561 | 222 | 0.781 | 0.0101 | 1062 |
| 25 | 22.4 | 7.27 | 3075 | 663 | 70.4 | 16.1 | 29.3 | 528 | 258 | 1.53 | 671 | 206 | <0.024 | 0.0054 | 1160 |
| 26 | 12.5 | 6.71 | 865 | 302 | 112 | 1.33 | 51.5 | 11.0 | 333 | 0.23 | 31.3 | 89.3 | <0.024 | 0.0586 | 491 |
| 27 | 16.1 | 6.62 | 738 | 179 | 89.6 | 2.94 | 38.8 | 17.4 | 189 | 0.23 | 36.6 | 144 | 1.67 | 0.0378 | 434 |
| 28 | 12.4 | 6.87 | 854 | 117 | 115 | 1.60 | 47.2 | 10.0 | 296 | 0.33 | 19.1 | 146 | 2.74 | 0.0524 | 518 |
| 29 | 13.3 | 6.80 | 1631 | 83 | 88.9 | 16.7 | 49.2 | 192 | 307 | 0.54 | 215 | 207 | 0.034 | 0.0097 | 767 |
| 30 | 16.6 | 7.04 | 1645 | 17 | 57.0 | 18.1 | 31.4 | 246 | 316 | 1.21 | 300 | 38.3 | <0.024 | 0.0020 | 643 |
| 31 | 22.6 | 7.29 | 2564 | 150 | 84.7 | 16.3 | 34.5 | 448 | 218 | 1.98 | 190 | 786 | 0.154 | 0.0030 | 1253 |
| 32 | 12.5 | 6.89 | 681 | 129 | 86.0 | 3.59 | 36.1 | 15.8 | 373 | 0.53 | 1.64 | 0.43 | 2.07 | 0.0475 | 362 |

Note: TDS was calculated. ND = Not Determined.

Table A3. Selected Minor Ions and Stable Isotopes for Sampled Wells. Results in mg/L unless otherwise specified

| Well # | B | Ba | $Br^-$ | $CH_4$ | Li | $NH_4$-N | Sr | $\delta^{13}C$_DIC (‰) | $\delta D$ (‰) | $\delta^{18}O$ (‰) | $\delta^{34}S\_SO_4$ (‰) | $\delta^{18}O\_SO_4$ (‰) | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.765 | 0.0316 | 1.52 | ND | 0.13 | 1.27 | 2.74 | -9.13 | -64.9 | -9.44 | 21.0 | 14.5 | 0.70976 |
| 2 | 0.722 | 0.0327 | 1.44 | 0.012 | 0.13 | 1.23 | 2.49 | -9.05 | -67.7 | -9.68 | 19.1 | 13.8 | 0.70966 |
| 3 | 0.821 | 0.0327 | 1.61 | 0.13 | 0.14 | 1.21 | 2.33 | -9.53 | -69.0 | -9.92 | 18.7 | 13.9 | 0.70963 |
| 4 | 1.86 | 0.0363 | 4.50 | 0.051 | 0.26 | 1.26 | 1.53 | -10.24 | -59.3 | -8.80 | 30.9 | 15.4 | 0.70978 |
| 5 | 0.669 | 0.0340 | 1.09 | 0.0054 | <0.11 | 1.07 | 3.44 | -9.16 | -58.6 | -8.76 | 19.2 | 14.7 | 0.70981 |
| 6 | 0.956 | 0.0398 | 1.63 | 0.013 | 0.15 | 1.04 | 2.28 | -9.41 | -66.2 | -9.70 | 20.2 | 14.0 | 0.70988 |
| 9 | 0.980 | 0.147 | 1.46 | 0.10 | 0.13 | 0.86 | 2.18 | -10.94 | -53.4 | -7.99 | 35.6 | 14.4 | 0.71018 |
| 10 | 1.08 | 0.0438 | 1.82 | 0.07 | 0.13 | 0.88 | 2.27 | -10.93 | -55.1 | -8.27 | 23.7 | 14.7 | 0.71020 |
| 11 | 0.946 | 0.0178 | 0.72 | 0.042 | 0.18 | 1.20 | 1.49 | -9.99 | -83.5 | -11.70 | 17.4 | 13.4 | 0.70958 |
| 12 | 0.730 | 0.0294 | 1.69 | ND | 0.14 | 1.43 | 5.14 | -11.01 | -62.6 | -8.95 | 18.7 | 15.0 | 0.70980 |
| 13 | 0.884 | 0.0162 | 0.87 | 0.024 | 0.15 | 1.18 | 1.95 | -10.52 | -76.8 | -10.84 | 17.2 | 13.1 | 0.70962 |
| 14 | 1.21 | 0.0109 | 0.60 | 0.012 | 0.26 | 1.34 | 3.34 | -9.07 | -92.4 | -12.68 | 18.5 | 13.1 | 0.70978 |
| 24 | 0.724 | 0.0342 | 1.80 | 0.37 | 0.14 | 1.32 | 4.16 | -9.69 | -65.0 | -9.36 | 18.9 | 15.2 | 0.70982 |
| 25 | 0.812 | 0.0356 | 1.96 | 3.0 | 0.14 | 1.22 | 3.95 | -9.89 | -64.6 | -9.20 | 18.8 | 15.2 | 0.70984 |
| 26 | 0.051 | 0.0466 | <0.08 | 0.0002 | <0.11 | <0.03 | 0.133 | -8.46 | -50.1 | -7.82 | -3.6 | 0.1 | 0.71053 |
| 27 | 0.086 | 0.0543 | <0.08 | 0.001 | <0.11 | <0.03 | 0.200 | -9.92 | -45.3 | -7.03 | -1.1 | 1.2 | 0.71058 |
| 28 | 0.038 | 0.134 | <0.08 | 0.074 | <0.11 | 0.56 | 0.308 | -7.52 | -48.6 | -7.52 | -11.2 | -1.0 | 0.70928 |
| 29 | 0.490 | 0.0246 | 0.74 | 0.17 | <0.11 | 0.71 | 2.09 | -10.53 | -55.4 | -8.28 | 21.7 | 14.6 | 0.71018 |
| 30 | 0.766 | 0.184 | 1.02 | 0.19 | <0.11 | 0.92 | 2.23 | -10.72 | -52.8 | -7.94 | 25.1 | 8.0 | 0.71002 |
| 31 | 1.19 | 0.0106 | 0.43 | 0.012 | 0.27 | 1.38 | 3.66 | -8.19 | -94.7 | -12.98 | 18.4 | 13.0 | 0.70977 |
| 32 | 0.174 | 0.0933 | <0.08 | 3.6 | <0.11 | 0.88 | 0.645 | -6.83 | -50.1 | -7.73 | ND | ND | 0.70967 |

Note: ND = Not Determined.